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Evaluation of the Fire Performance of Carpet Underlayments

Susan Alderson and Leslie Breden

Center for Fire Research
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U. S. DEPARTMENT OF COMMERCE

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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*

Edward O. Vetter, *Under Secretary*

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

CONTENTS

LIST OF FIGURES (cont'd)

LIST OF TABLES

SI CONVERSION UNITS

In view of present accepted practice in this technological area, U.S. customary units of measurement have been used throughout this report. It should be noted that the U.S. is a signatory to the General Conference on Weights and Measures which gave official status to the metric SI system of SI units in 1960. Readers interested in making use of the coherent system of SI units will find conversion factors in ASTM Standard Metric Practice Guide, ASTM Designation E 380-72 (available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103). Conversion factors for units used in this paper are:

<u>Length</u>

1 in = 0.0254* meter
1 ft = 0.3048* meter

<u>Area</u>

1 in^2 = 6.4516* x 10^{-4} $meter^2$
1 ft^2 = 9.2903 x 10^{-2} $meter^2$

<u>Volume</u>

1 gal = 3.8 liters

<u>Mass</u>

1 lb = 0.4536 kg

<u>Density</u>

1 lb cu ft = 0.016 g/cc

<u>Energy</u>

1 Btu = 1054.8 J
1 Btu/lb = 2.326 kJ/kg

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*Exact Value

Temperature

°C = 5/9 (Temperature °F - 32)

Power

1 Btu/min = 17.57 W

Time

1 min = 60 s

EVALUATION OF THE FIRE PERFORMANCE OF CARPET UNDERLAYMENT

Susan Alderson and Leslie H. Breden

Abstract

A series of carpet underlayments was evaluated for fire performance in a corridor configuration using the same carpet in all tests. Carpets with underlayments flashed over during corridor tests. In a series of small-scale tests, such as the smoke density chamber and the radiant panel, the flammability properties of the carpet tended to mask the flammability properties of the underlayment. The exception to this masking effect was the results from the flooring radiant panel test where the thermal conductivity of the underlayment influenced the burning characteristics of the carpet. High concentrations of toxic combustion products were observed at the time of flashover in the corridor, with both cellulosic and synthetic underlayments. Smoke optical density values for the various carpet plus underlayment combinations were approximately the same in the flaming mode, except for the integral pad system which has a higher value.

Key words: Carpets; fire; flammability; floor coverings; pad; underlayments.

1. INTRODUCTION

The current mandatory carpet flammability standard, Department of Commerce FF 1-70, uses the methanamine pill test to keep easily ignited carpets off the market. In some cases, however, such as in institutional buildings, multiple occupancy buildings, and other special occupancies, a more severe test of carpet performance may be desirable. The purpose of this study was to determine the effect of an underlayment on the spread of fire on carpet in a corridor when the fire originates in a room adjacent to the corridor, and to correlate the results of these tests with the results of small-scale laboratory tests. The corridor configuration is an experimental simulation to investigate fire spread in full-scale, and is not a test method to evaluate carpets or underlayments.

2. EXPERIMENTAL DESIGN

2.1. Large-Scale

Five different carpet underlayments which were covered by the same carpet, were evaluated for fire performance in a corridor configuration. For example, the maximum temperature at flashover could be examined for each underlayment as well as the products of combustion. In addition,

the effect of underlayments on the results of a small-scale test such as the flooring radiant panel, could also be evaluated. A detailed description of the experiments is given below.

2.1.1. Description of the Corridor

Schematic drawings of the NBS corridor facility are shown in figures 1, 2, and 3. The corridor has been described extensively by other workers [1,2][1].

The corridor is 30 feet long, 8 feet wide, and 8 feet high. At one end of the corridor there is a doorway connecting to a burn-room where a crib fire is initiated. The walls and the ceiling are constructed of 1/2-inch low density cement-asbestos board on steel studs covered by 5/8- inch gypsum wall board. The subflooring consists of 1/4-inch high density cement-asbestos board on a brick base. An exit window 70 inches by 41 inches is located at the far end of the corridor. Part of the air needed for combustion of the cribs enters the burn-room through the door from the corridor. Air enters the corridor along the floor and then into the burn room. The hot combustion products from the burn-room flow out along the corridor ceiling and, finally, out the top of the exit window as shown in figure 4.

2.1.2. Description of the Burn-Room

A view of the burn-room is shown in figure 5. The burn-room is of concrete block construction, 9.3 x 7.7 x 8.4 ft high, with a door opening of 6.5 x 2.5 ft. Located 1 foot above the floor of the burn-room are two small vents 7 x 14 in. These vents are open to the atmosphere and supply a portion of the combustion air. The burn-room interior is sprayed with a one-inch thick protective coating of refractory material over the concrete block. This coating has the following thermal properties:

Density	18.5	lb/ft^3
Thermal Conductivity	0.057	Btu/hr °F
Specific Heat	0.2	Btu/hr °F
Thermal Diffusivity	0.0015	ft^2/hr

2.1.3. Description of Wood Cribs

Full-scale experimental fires for room simulation suggest that wood cribs present a realistic fire severity [3]. Four hemlock wood cribs were used to simulate burning objects in a room. The cribs are made of sticks 1-1/2 inches wide with a cross stick spacing of 3 inches (see figure 3). There are 4 sticks in each layer, with 16 layers, except the bottom layer which has 2 sticks. The 4 cribs are oven dried to a moisture content of

[1]Numbers in brackets refer to the references listed at the end of this paper.

approximately ten percent. They are placed in the burn-room on a load cell platform. To initiate the experiment, they are ignited by 250 ml of heptane placed in a pan under each crib. Each crib weighs approximately 42.5 lbs with a total weight for the four cribs of 170 lbs. The four cribs provided a fuel loading of 2.7 lbs per square of floor area and each have a maximum burn rate of 12.5 lbs of wood per minute, maintaining this rate for 8 to 11 minutes, as shown in figure 6.

2.1.4. Description of the Instrumentation

Table 1 outlines the measurements taken in the burn-room and the corridor. Chromel-alumel type thermocouples are used to measure temperature. Pitot tubes at the top of the burn-room and exit doors measured the combustion product velocities while the bottom pitot-static tubes measured the inlet airflow. Radiometers are mounted in the floor of the corridor to monitor incident flux. In addition, there is a radiometer mounted on the wall monitoring radiation in the burn-room. Heat flux meters are also used to measure heat loss through the walls. Finally, the cribs are placed on a load cell platform so that the burning rate of wood cribs can be measured. All measurements are recorded by a high speed digital data acquisition system. This system recorded all inputs at 20-second intervals with seven recording points per second.

Two methods of gas sampling were employed to analyze the atmosphere in the corridor:

1. continuous measurement of O_2, CO_2, and CO concentrations; and
2. grab samples which were collected in pre-evacuated 2-liter glass bulbs for later laboratory analysis.

The continuous measurements of CO and CO_2 were made with non-dispersive infrared instruments. These instruments were calibrated with known gas mixtures and calibration curves developed since the instrument readout was nonlinear. To protect the non-dispersive infrared instruments, the sample line contained a series of traps. As the sample was drawn from the corridor, it entered a glass wool ambient trap for removal of the majority of particulate matter. A sub-ambient dry ice trap also packed with glass wool was used to eliminate the water. Finally, a third glass wool trap maintained at ambient temperatures was used as a back-up for any overflow of particulate matter before the gas entered the analyzers. A stainless steel line was used from the sampling point in the corridor into the cold trap and either copper or polyethylene tubing was used from that trap to the analyzers. The delay time was considered insignificant with respect to the response of the instrument.

An electrolytic diffusion O_2 cell was used to measure the O_2 depletion. These cells have been reliable, but some problems were encountered requiring frequent regeneration of the cell. The O_2 cells, and CO_2 analyzers were directly attached to a Vidar System. The data were stored on a magnetic tape and processed by computer.

Table 1. Corridor Instrumentation

TC Center of Burn-Room Ceiling
TC Ceiling of Corridor 01 ft from CL of Doorway
TC Corridor CL Ceiling 02 ft from West Wall
TC Corridor CL Ceiling 05 ft from West Wall
TC Corridor CL Ceiling 10 ft from West Wall
TC Corridor CL Ceiling 15 ft from West Wall
TC Corridor CL Ceiling 20 ft from West Wall
TC Corridor CL Ceiling 25 ft from West Wall
TC Pitot Tube No. 1
TC Pitot Tube No. 2
TC Pitot Tube No. 3
TC Pitot Tube No. 4
TC Pitot Tube No. 5
TC Pitot Tube No. 6
TC Pitot Tube No. 7
TC Pitot Tube No. 8
Pitot Tube No. 1 Burn-Room Door
Pitot Tube No. 2 Burn-Room Door
Pitot Tube No. 3 Burn-Room Door
Pitot Tube No. 4 Burn-Room Door
Pitot Tube No. 5 Burn-Room Door Bottom
Pitot Tube No. 6 East Window
Pitot Tube No. 7 East Window
Pitot Tube No. 8 East Window
TC 5 ft String 1 ft from Ceiling
TC 5 ft String 2 ft from Ceiling
TC 5 ft String 3 ft from Ceiling
TC 5 ft String 5 ft from Ceiling
TC 5 ft String 6 ft in from Floor
TC 25 ft String 1 ft from Ceiling
TC 25 ft String 2 ft from Ceiling
TC 25 ft String 3 ft from Ceiling
TC 25 ft String 5 ft from Ceiling
TC 25 ft String 6 in from Floor
O_2 Burn Door
O_2 20 ft Ceiling
TC Ref
Load Cell
Radiometer No. 1
Radiometer No. 2
Heat Fluxmeter No. 1
Heat Fluxmeter No. 2
Heat Fluxmeter No. 3
Heat Fluxmeter No. 4
CO 20 ft
CO_2 20 ft
TC Door CL .5 ft
TC Door CL 2 ft
TC Door CL 4 ft
TC Door CL 6.5 ft
CL Floor 5 ft from West Wall
CL Floor 9 ft from West Wall
CL Floor 13 ft from West Wall
CL Floor 17 ft from West Wall
CL Floor 21 ft from West Wall
CL Floor 25 ft from West Wall
Seconds

In addition to these measurements, a bubbler system was used to collect HCN. Two bubblers were used in series, each containing 200 cc of 0.1 N NaOH. The flow rate averaged 2 liters/minute. Analysis of the NaOH solution was done using both specific ion electrode methods and the colorimetric technique according to Leithe [4]. The sample point for the HCN analysis was 20-ft from the entrance of the corridor and approximately 2 feet from the ceiling. The sample line from the bubbler to the sampling port was 2 feet-8 inches.

The grab samples were taken at the 20-ft position: the first at 5 min, 1 inch from the ceiling; the second and third samples at 10 min, the second 1 inch from the ceiling and the third 4 feet from the ceiling. The fourth was taken at 15 min, or at "flashover," whichever occurred first (1 foot from the ceiling). The flasks were attached by a 19/9 ball joint to 2.5 inches of pyrex tubing which was approximately 1 foot long and went through the wall. These samples were not filtered; therefore, smoke, particulate matter, and gases were collected together.

The grab samples were analyzed using a Perkin-Elmer 457 infrared spectrophotometer. A one-meter gas cell was used. The measured percent transmittance was sensitive to pressure; therefore, all the samples were run at 100 torr pressure. Calibration curves were developed based upon peak height and were used for semi-quantitative results. The gases analyzed in this way were CO, CO_2, CH_4, C_2H_4, C_2H_2, and HCN.

2.1.5. Description of the Carpet

The carpet used in this experiment was standard for all the tests and was composed of 3-ply nylon yarn with a total weight of 56 oz/yd^2. The face fiber has a weight of 22 oz/yd^2. The pile height was .177 inches with a tufted gage of 1/10 inch and 7 stitches per inch. The primary backing was polypropylene filament with a jute secondary backing. The carpet had a potential heat of combustion of 6968 Btu/lb.

2.1.6. Description of the Underlayment

Five different types of underlayments were examined — hair jute, virgin urethane, rebonded urethane, integral latex with alumina trihydrate filler, and styrene-butadiene rubber containing calcium carbonate and naphthenic oil. Their corresponding densities and thermal conductivity were respectively, 8.8, 2.6, 5.2, 17.7, 4.2 lbs/ft^3 and 0.29, 0.18, 0.23, 0.45 and 0.38 Btu/hr/ft^2/F°/in. The underlayments were 1/2 inch thick except for the integral latex and the SBR and waffle pads which were 3/16 inch thick. The hair jute was not treated for fire retardancy while the virgin urethane and the rebonded urethane contained a phosphorus type flame retardant. The virgin and rebonded both had a 0.0075-inch film of low density polyethlene on the surface. The carpet was placed directly over the underlayment except for experiments 362, 363, and 365 where a chloroprene type of adhesive was used to bond the carpet to the underlayment.

2.1.7. Procedure

A blank run (No. 355), was made with four cribs in the burn-room, and a cement-asbestos board floor in the corridor. Metal cans filled with 250 g of heptane were used to ignite the cribs. Measurements were taken with these burning cribs alone. This procedure was repeated with the nylon carpet in the corridor over the cement-asbestos board (No. 356). The experiment was then repeated with the carpet laid down over various pads or adhered to a pad for the length of the corridor. When carpeting was used, a piece of carpet, 2 x 4 ft, was extended into the burn-room under the cribs. This piece provided for a continuous path for the flame to spread into the corridor. Eleven tests were conducted. The details are given in table 2.

2.1.8. Description of Flashover Phenomena in the Corridor

A test commences with the ignition of the four cribs in the burn-room. In several minutes the crib fire reaches a fairly steady burning rate. Approximately half of the air required to support crib combustion flows into the burn-room through the two floor level vents, while the remaining air supply enters from the corridor [5]. Products of combustion flow from the room along the corridor heating its walls and ceiling. Inlet air flows over the corridor floor. The floor is heated by radiative transfer from upper hot walls and ceiling and the hot smoke products. Three to four minutes after the crib is ignited, ignition occurs on a 2-1/2 ft wide floor covering runner which extends from the corridor into the burn-room. This ignition results from a high radiant heating exposure over this runner and from the flaming crib embers falling onto the carpet. Once ignition occurs on the runner, rapid flame spread follows over the entire runner in the burn-room. This flooring fire then emerges and spreads slowly into the corridor. The flame fans out from the doorway advancing against the incoming airflow and progresses under the radiant heating of the floor from the walls, ceiling, and hot smoke layer.

As the fire on the floor advances it consumes some of the oxygen of the incoming air. Flashover in the corridor occurs in the gaseous phase and ignites the carpet. The occurrence of flashover in the corridor is preceded by a reduction in air supply from the corridor to the burn-room so that the crib fire becomes fuel rich. The crib fire continues to produce pyrolysis products, but incomplete combustion products enter the corridor followed by rapid flame spread within the corridor. The flashover from the combustion of the carpeting produces a large increase in the corridor temperature and heat flux.

3. OBSERVATION AND RESULTS

A series of carpet underlayment experiments were carried out. The results are summarized in table 2. It should be noted that due to the extensive building renovation at the time, extraneous variables may have

Table 2. Summary of Corridor Experiments

Test No.	Floor Linings	Underlayment	Subflooring	Number of Cribs	Flashover Time, (s)
355	None	None	1/4" Cement-Asbestos Board on Brick	4	No Flash-over
356	Nylon	None	"	4	No Flash-over
357	Nylon	Hair Jute	"	4	No Flash-over
358	Nylon	Virgin Ure-thane	"	4	No Flash-over
361	Nylon	Rebonded Ure-thane	"	4	810
332	Nylon	Rebonded Ure-thane & Adhe-sives	"	4	600
363	Nylon	Virgin Urethane & Adhesives	"	4	720
364	Nylon	Latex	"	4	690
365	Nylon	Virgin Urethane	"	4	630
367	Nylon	SBR Waffle	"	4	690
368	Nylon	Hair Jute	"	4	810

Table 2a.

Experiment No.	Material	Maximum Peak Temp. at 5 ft, 1 ft from the Ceiling (°C)	Maximum Peak Temp. at 25 ft, 1 ft from the Ceiling (°C)
361	Nylon carpet and rebonded urethane	689	937
364	Nylon carpet and latex	779	898
365	Nylon carpet and virgin urethane	776	828
367	Nylon carpet and SBR	769	969
368	Nylon carpet and hair jute	733	879

been introduced into the tests. For example, new smoke abatement equipment was intermittantly used on some of the corridor runs. Also, prior to run No. 358, the wall temperature was not controlled because the outside air was allowed to circulate throughout the test facility before testing. Since these experiments were carried out at various times of the year, the temperature and humidity in the corridor was not maintained constant before testing. Finally, due to leaks in the cooling water lines needed for our instrumentation, such as in the heat flux meter, there may have been some water contamination on the carpet in several of the early runs.

3.1. Crib Burning

The crib burning rates are shown in figures 7 and 8. Essentially, the cribs reached a steady-state burning rate after 3 to 5 minutes. The time variation between tests was attributed to the variable moisture content and the non-homogeneity of the wood. After this initial lag period, the steady-state burning rate remained constant for 8 to 11 minutes. With a fuel loading of 170 lbs of wood and a heat of combustion energy content of 7,200 Btu/lb, the potential heat available is calculated to be 1,250,000 Btu. However, it must be assumed that incomplete combustion occurs and the total available energy would be about half of this amount [1]. It has been estimated by Christian and Waterman that a bedroom fire would have a steady burning rate of 110,000 Btu/min [5].

A comparison of the burning rates of the cribs indicated no significant differences between runs. Fung and others have shown that with the refractory material as the burn-room coating, it appears that the heat loss of the cribs to the burn-room surface by conduction is only significant during the early phase of burning. For the rest of the run, the heat loss by conduction to the room is about 15% of the total heat release. The radiant energy contribution to the energy supply to the corridor is about 10% of the total energy transport into the corridor, since the corridor only sees the burn-room fire through the doorway. Thus, the bulk of the energy released (75%) from the cribs enters the corridor in the form of convective energy out of the burn-room doorway.

3.2. Flame Spread in Corridor

During the period of maximum burning, the fire plume extended out from the burn-room and licked the corridor ceiling near the burn-room. As the fire progressed out of the burn-room, it was preceded by a melting of the carpet just ahead of the flame front. This same melt phenomena was observed in the flooring radiant panel tests. The nylon carpet has a melt temperature of approximately 215 °C.

Figures 9 through 18 illustrate a comparison of corridor runs 357 and 368. The same type of nylon carpet over a hair jute underlayment was used in both, however run 357 did not flashover while 368 did. Figure 9 shows that the rate of weight loss of the crib was approximately the same, with the slopes being almost parallel in the steady-state region of burning. The similarity of the burning cribs is also reflected in the ceiling temperature of run 357. Figure 11 shows the almost congruent ceiling temperature in the corridor for the two experiments. Figures 12 and 13 also show exactly the same tracking profile for the corridor temperature at the 5-ft and 25-ft stations. It should be noted from figure 14 that the peak temperature on the floor 5 ft from the west wall was greater in run 357, which did not flashover, than run 368, which did flashover. A comparison of floor temperatures down the corridor, as illustrated in figure 15, also indicates that the peak temperature was slightly higher for 357 than 368. Figures 16, 17 and 18 illustrate the slight variance between runs using other measurement parameters.

It appears that the thermal energy in run 357 should have been sufficient for flashover to occur corresponding to 368; however, run 357 did not flashover. A similar analysis showed the same results when tests 358 and 365 are compared. That is, thermally, 358 should have had the potential to flashover; but it did not.

A comparison was also made of runs 361 to 368 using various measurement parameters. Figure 19 illustrates the burning weight loss of the wood cribs used in all 5 runs. The cribs with the hair jute underlayment had a slightly higher burning rate than the other underlayment runs.

Generally, the steady-state burning weight loss was 10 to 12 pounds per minute for all runs. The ceiling temperatures in the burn-room for these 5 runs are shown in figure 20. In terms of heat input, test 364 (latex) had the highest ceiling temperature (1031 °C) while test 365 (virgin urethane) had the lowest (757 °F). Figures 21, 22, 23 and 24 illustrate the ceiling temperature down the corridor. The burning virgin urethane underlayment appeared to contribute some additional heat, which may have caused the carpet to reach the flashover condition sooner. This is evidenced by the virgin urethane having the shortest flashover time of the nonadhered underlayments of 630 seconds compared to 810 seconds for the rebonded and the hair jute underlayments, shown in table 2. Figures 25, 26 and 27 show the virgin urethane underlayment with the highest rate of temperature rise 1, 2 and 3 feet below the ceiling at 5 feet down the corridor. The plateau region at 300 °C to 400 °C is attributed to the melting of the nylon carpet. This represents a temperature transitional zone with the melt temperature of the nylon carpet fiber being between 216 °C and 260 °C, while the decomposition temperature was 316 °C. Tables 3 and 4 also show the relative times to reach to maximum temperature and the time to reach 500 °C.

It appears the temperature profile for all of the runs were similar before flashover with the exception of the virgin urethane and the latex.

As previously described in section 2.1.8., it appears that substantial amounts of combustible products from the cribs were being generated which were not burned. It is the accumulation of these fuels which later become heated to above 600 °C and contribute to a flashover condition. Calculations by Quintiere [6] indicate that there is enough oxygen in the airflow to maintain the burning of the wood cribs, but not enough to completely burn all of the volatile fuel.

Figures 28, 29 and 30 illustrate the temperature profile 5 feet down the corridor from the burn-room at ceiling and the floor level. The fresh air entering along the floor acts to reduce the temperature 1 foot above the floor; however, this cooling effect is lost with the onset of flashover.

3.3. Gas Sampling

The results of the grab sample analysis with the materials tested are shown in tables 5 and 6. In the first four tests, no "gas phase flashover" occurred and the only gases detected in the grab samples in any significant amount were CO and CO_2. From the fifth test on, "gas phase flashover" did occur with an accompanied increase in the amount of hydrocarbons in the grab samples. Two tests were repeated, that of nylon carpet with virgin urethane underlayment and nylon carpet with hair jute underlayment. The grab samples indicated that an increase in the amount of hydrocarbons occurred earlier in the tests when flashover took place. The buildup of these combustibles in the gas phase seems to be a necessary element for the "flashover."

Table 3. Maximum Temperature before Flashover

Test	Corridor CL Ceiling 2 ft from W Wall	Corridor CL Ceiling 5 ft from W Wall	Corridor CL Ceiling 10 ft from W Wall	5 ft String 1 ft from Ceiling	5 ft String 3 ft from Ceiling	5 ft String 5 ft from Ceiling	25 ft String 1 ft from Ceiling	25 ft String 3 ft from Ceiling	25 ft String 6 in from Floor	CL Floor 5 ft from W Wall	CL Floor 9 ft from W Wall	CL Floor 17 ft from W Wall
361 Temp. (°C)	959	952	896	935	944	949	937	951	972	866	869	900
Time (s)	740	740	740	740	730	730	750	760	750	730	730	750
364 Temp. (°C)	911	932	877	974	855	980	1019	997	852	928	838	507
Time (s)	630	630	620	630	640	630	660	660	660	570	620	660
365 Temp. (°C)	972	947	945	996	1018	1000	1014	970	698	841	872	500
Time (s)	470	580	590	570	580	580	610	610	610	580	530	610
367 Temp. (°C)	998	992	965	1016	976	961	969	885	530	897	789	508
Time (s)	790	810	830	780	790	810	840	840	840	770	810	840
368 Temp. (°C)	937	947	903	996	991	960	941	853	765	879	747	646
Time (s)	710	700	730	690	710	710	740	740	740	560	720	730

Table 4. Time to Reach 500 °C in Seconds

Test	Corridor CL Ceiling 2 ft from W Wall	Corridor CL Ceiling 5 ft from W Wall	Corridor CL Ceiling 10 ft from W Wall	5 ft String 1 ft from Ceiling	5 ft String 3 ft from Ceiling	5 ft String 5 ft from Ceiling	25 ft String 1 ft from Ceiling	25 ft String 3 ft from Ceiling	25 ft String 6 in from Floor	CL Floor 5 ft from W Wall	CL Floor 9 ft from W Wall	CL Floor 17 ft from W Wall
361 (s)	210	230	530	470	510	680	560	660	740	520	660	700
364 (s)	260	450	440	270	420	460	450	480	650	440	560	650
365 (s)	200	360	410	330	430	460	450	480	610	440	510	610
367 (s)	250	560	630	430	610	670	640	680	840	620	700	840
368 (s)	280	510	550	470	540	640	570	660	710	520	660	720

Table 5. Grab Sample Infrared Data

Experiment No.	Material	Time Sec/ Position [a]	% CO	% CO_2	% CH_4	% C_2H_4	% C_2H_2	Estimated % HCN	Flash-time
355	Wooden Ignition Cribs	300 a	0	7.5	0	0	0	0	
		600 d	1.5	10.2	0	0	0	0	N.F.[b]
		900 b	0	1.5	0	0	0	0	
356	Nylon Carpet	300 a	0	11.5	0	0	0	0	
		600 b	1.2	10.0	0	0	0	0	N.F.
		600 c	1.0	5.0	0	0	0	0	
		900 d	1.0	9.5	0	0	0	0	
357	Nylon Carpet Hair Jute Pad	300 a	3.0	14.5	0.7	0.1	0.2	0	
		600 c	2.0	9.0	0	0	0	0	N.F.
		900 d	1.5	11.0	0	0	0	0	
358	Nylon Carpet Virgin Urethane Pad	300 a	0	3.0	0	0	0	0	
		600 b	0.3	3.2	0	0	0	0	N.F.
		600 c	0.5	3.2	0	0	0	0	
		900 d	0	3.6	0	0	0	0	
361	Nylon Carpet Rebonded Urethane Pad	300 a	2.8	13.5	.1	0	0	0	
		600 b	2.0	10.0	+	0	0	+	810
		600 c	2.0	9.5	+	0	0	+	
		810 d	5.0	18.3	1.3	3.5	0.60	.5	
362	Nylon Carpet Rebonded Urethane Pad Sealed with Latex Glue	300 a	1.0	13.0	0	0	+	0	
		600 b	2.2	14.5	0	0.4	0.4	0.4	600
		600 c	3.5	13.8	0.5	0.2	0.4	0.3	
		600 d	5.2	19.2	1.4	0.7	1.1	0.7	
363	Nylon Carpet Virgin Urethane Pad Sealed With Latex Glue	600 a	1.0	11.0	0	0	0	+	
		600 c	.5	10.0	0	0	0	+	720
		720 d	5.5	17.8	1.4	0.6	1.1	0.8	
364	Nylon Carpet Latex Pad	300 a	2.5	17.0	0.1	0	0	0	
		600 b	2.0	14.0	0	0	+	0.1	690
		600 c	0	9.5	0	0	0	0	
		690 d	4.5	17.0	0.8	0.3	0.6	0.7	
365	Nylon Carpet Virgin Urethane Pad	300 a	2.8	12.5	0.1	0	+	+	
		600 b	4.3	17.5	0.6	0.3	0.5	0.4	630
		630 d	5.2	18	1.8	1.0	0.8	0.8	
367	Nylon Carpet SBR Attached Rubber Backing	300 a	2.0	12.5	0	0	0	0	
		600 b	1.0	10.5	0	0	0	0	690
		600 c	1.0	7.5	0	0	0	0	
		690 d	4.0	17.0	0.8	0.2	0.6	0.4	
368	Nylon Carpet Hair Jute Pad	300 a	2.2	13.5	0.1	0	+	0	
		600 b	1.2	11.0	0	0	+	+	810
		600 c	1.0	8.0	0	0	0	+	
		810 d	4.5	14.5	1.0	0.7	0.6	0.7	

[a] Positions designated: a-1" from ceiling; b-1" from ceiling; c-4' from ceiling; d-1' from ceiling.

[b] No Flashover

Table 6. Comparison of Results Between the Specific Ion Electrode Method and the Colorimetric Technique for Hydrogen Cyanide Analysis

Floor Covering	Experiment Number	Specific Ion Electrode Method	Colorimetric Method
Nylon Carpet Virgin Urethane Pad & Adhesive	363	0 ppm	1 ppm
Nylon Carpet Latex Pad	364	45 ppm	69 ppm
Nylon Carpet Virgin Urethane Pad	365	90 ppm	82 ppm
Nylon Carpet SBR Waffle Pad	367	<1 ppm	2 ppm
Nylon Carpet Hair Jute Pad	368	16 ppm	21 ppm

The correlation between the continuous monitoring shown in figure 31, 32 and 33 and the grab sample data is not apparent. Both the grab samples and continuous monitors were positioned 20 feet away from the ignition source — the continuous sample line being in the center of the corridor 1 foot from the ceiling, while the grab samples were taken on the left side of the corridor at various heights. In a large-scale facility such as the corridor there is a problem with variable and nonuniform mixing of the gases. The gases were also handled differently. The continuous sample traveled through at least 34 feet of tubing and three traps — two ambient and one subambient. Most of the water and particulate matter was removed before the sample reached the analyzers. The grab samples were not filtered and, therefore, included water, smoke, particulate matter, and gases which were drawn directly out of the corridor through a tube 1 foot long. These samples were then taken to the laboratory for analysis.

The comparison of the concentration values of CO and CO_2 recorded from the grab samples and continuous monitoring equipment shows a large discrepancy in all but the last test. The different treatment coupled with differing sampling positions might be an explanation. Test 368 (figure 33), which involved a nylon carpet with hair jute padding, grab sample data and continuous monitoring gas data seemed to correlate much more closely.

The gas analysis data in these tests identifies some of the components present during the burning of carpet and underlayment. The hazard associated with these components in a practical situation has not yet been defined.

4. SMALL-SCALE TESTS

4.1. Pill Test

This test method is designed to prevent the ignition of carpets and rugs from small sources such as matches, fireplace embers, or inadvertently discarded lighted cigarettes. The test is extensively described in DOC FF 1-70. A methenamine pill is placed in the center of a dried carpet sample and ignited. The surface burning of the carpet is then measured with a failure described when the surface burning reaches within one-inch of an eight-inch diameter circle. The nylon carpet alone, and when placed over any of the underlayments, passed the pill test.

4.2. Smoke Density Chamber Test (NFPA 258T)

This test method measures the attenuation of a light beam by smoke accumulating in a closed chamber due to smoldering decomposition or flaming combustion. The results are reported in terms of maximum optical density which is a dimensionless number expressed as follows:

$$D_m = \frac{V}{AL} \log \frac{100}{T}$$

where D_m = maximum optical density

V = volume of chamber (18 ft^3)

A = surface area of specimen (0.046 ft^2)

L = path length of attenuation (3 ft)

T = percent transmittance

Measurements were taken from 3 x 3 inch specimens under a radiant flux of 2.5 watts per square centimeter in a flaming and smoldering condition. A schematic diagram of the NBS Smoke Chamber is shown in figure 13. The smoke level of underlayments was measured individually and with a carpet. The results are shown in tables 7 and 8.

The results indicate that in the smoldering mode, the carpet with underlayment always had a higher smoke value than the carpet alone. Tested alone, the waffle and the integral pads had high maximum optical density values. It should be noted that in the smoldering mode, hair jute, alone, had a significant loss of weight and took a long time to reach the maximum smoke development when compared to the other underlayments.

Table 7. NBS Smoke Chamber - Smoldering

Smoldering Decomposition	Maximum Optical Density	Weight Loss (g)	Time (min)	Percent Weight Loss (g)	Observations
Hair Jute	336	6.37	17.33	69.67	Small amount of liquid residue
Virgin Urethane	219	1.57	8.00	44	Large amount of liquid residue
Rebonded Urethane	248	2.51	11.33	40	Large amount of liquid residue
SBR Waffle	644	2.96	7.75	24	Large amount of liquid residue
Latex	503	---	8.00	--	---
Carpet	269	3.53	19.33	27	Flames after 3.5 minutes
Carpet & Hair Jute	410	10.44	30.33	44	Gray dust on floor of chamber
Carpet & Virgin Urethane	287	6.18	41.67	36	Large amount of liquid residue
Carpet & Rebonded Urethane	306	6.70	46.67	35	Large amount of liquid residue
Carpet & Waffle	403	7.45	44.67	29.33	---
Carpet & Latex	314	3.24	23.50	18.5	After 2.5 minutes flame started

Table 8. NBS Smoke Chamber - Flaming

Flaming Combustion	Maximum Optical Density	Weight Loss (g)	Time (min)	Percent Weight Loss (g)	Observations
Hair Jute	111	6.46	9.33	66	
Virgin Urethane	104	2.66	8.33	63	Large amount of residue dripping
Rebonded Urethane	---	5.01	7.67	73	Large amount of residue dripping
Latex	181	9.9	---	---	
SBR Waffle	265	3.63	1.92	29	
Carpet	211	5.02	2.25	37	
Carpet & Hair Jute	233	10.67	3.0	44	
Carpet & Virgin Urethane	214	5.80	2.50	32	Large amount of residue dripping
Carpet & Rebonded Urethane	227	5.93	2.83	30	Large amount of residue dripping
Carpet & Latex	338	6.80	3.17	---	No weight loss in pan
Carpet & Waffle	221	5.85	2.5	21.	No weight loss in pan

In the flaming mode, the smoke values of the carpet alone and with the underlayment are about the same. The exception is the integral latex pad system which had a significantly higher smoke value either with or without the carpet.

4.3. Thermogravimetric Analysis

Thermogravimetric analysis (TGA) involves changes in weight of a system under investigation as the temperature is increased at a predetermined rate. Samples of underlayments were conditioned for 24 hours at 23 °C, 50% relative humidity and placed in the TGA sample holder. The sample was heated at 10 °C per minute in air. Figures 34 to 38 illustrate the results from the TGA. Generally, all of the underlayments had a 50% weight loss by 300 °C. The initial weight loss of hair jute was attributed to absorbed water loss. The virgin and rebonded urethane underlayments gave uniform decomposition curves compared to the complex curve of SBR rubber underlayment.

4.4. Flooring Radiant Panel Test

A radiant panel test has been developed which determines the critical radiant flux at extinguishment of flooring systems. This test consists of a radiant panel placed at a 30° angle to a horizontal specimen as shown in figure 39. Measurements are taken of the distance burned which is related to the critical radiant flux at the time of extinguishment (figure 40). The initial flux level for the flooring radiant panel was based on the heat flux level found in the large-scale corridor tests prior to flashover.

The results, as shown in table 9, indicate that the underlayment significantly lowers the critical heat flux so that the carpets burn a greater distance. It appears that the heat transfer through the carpet is impeded by the underlayment thereby allowing more heat to be available for feedback in order to maintain the spread of fire. Thus, the carpet without the underlayment had a critical heat flux was 0.24, but with the underlayment it was reduced from 0.16 to 0.12.

Table 10 illustrates the effect of a hair jute pad on various types of carpets when tested with the flooring radiant panel test, showing the consistent decrease in critical flux when the pad is used to change the thermal properties of the system.

Thus, it appears that the thermal conductivity of the underlayment is one of the major factors in determining the horizontal surface flame spread along carpets.

Table 9. Carpet Underlayment Evaluation With the Flooring Radiant Panel Test

Carpet	Pad	Critical Flux W/cm^2	Comments
Nylon	Hair Jute	0.12	Very high flames and heavy black smoke. Melted to an average 38 cm.
Nylon	Virgin Urethane	0.14	High flames and heavy black smoke. Melted to an average 36.5 cm.
Nylon	Rebond	0.16	High flames and heavy black smoke. Melted to an average 36.5 cm.
Nylon	Integral Latex	0.13	Heavy black smoke. Buckled after 2.5 min. Melted to an average 27.5 cm.
Nylon	SBR Waffle	.13	Very high flames and heavy black smoke. Melted to an average 35 cm.
Nylon	___	.24	Thick black smoke. Melted to an average 27 cm.

Table 10. Flooring Radiant Panel Results of Carpet and Underlayment

Type of Material	Radiant Critical Flux (W/cm^2)
Wool	1.0
Wool and Hair Jute	0.66
Acrylic	0.41
Acrylic and Hair Jute	0.25
Nylon A	0.42
Nylon A and Hair Jute	<.10
Nylon B	0.61
Nylon B and Hair Jute	0.35
Polyester A	0.32
Polyester A and Hair Jute	<.10
Polyester B	0.24
Polyester B and Hair Jute	<.10

4.5. Thermal Conductivity

Thermal conductivity measurements were made of the carpet plus the underlayment by means of the guarded hot plate method in accordance with the procedure described in ASTM C177. This method covers thermal conductivity measurements of dry specimens using a hot metal center plate at 100 °C and two outside cold plates at 53 °C. A sample size of 8 x 8 inches was used with measurements taken of the carpet alone and with the underlayment. The heat flux, Q in the center and outside plates was rigidly controlled while the temperature difference between the hot and cold plates was measured. The smaller the K the better the insulation values of the material. The apparent thermal conductivity is calculated based upon $Q = K\Delta T\Delta X$

where
Q = heat flux
K = thermal conductivity
ΔT = temperature difference between the hot and cold plates
ΔX = thickness

It appears that the thermal conductivity of the carpet alone is significantly higher than any of the underlayments (table 11). The effect of lower thermal conductivity values is to prevent heat transfer out the back of the carpet and allow for more reinforcement of the burning to take place in the carpet. It appears that a similar situation exists in the corridor experiments, however, in the original experimental design of the corridor, this property of carpet or underlayment was not measured.

Table 11. Thermal Conductivity Measurements

Floor Covering	Temp (°F)	K (Btu/hr/ft^2/F°/in)
Carpet & Hair Jute	75.0	0.355
Carpet & Virgin Urethane	75.6	0.325
Carpet & Rebonded Urethane	75.6	0.320
Carpet & Integral Latex	71.2	0.554
Carpet & SBR Waffle	75.0	0.496
Carpet	68.5	0.780
Hair Jute		*0.29
Virgin Urethane		*0.18
Rebonded Urethane		*0.23
Integral Latex		*0.45
SBR Waffle		*0.38

*All of the thermal conductivity measurements and calculations were carried out by Mr. Chuck Sui at NBS.

5. CONCLUSIONS

1. Each of several underlayments used in combination with a standard carpet caused flashover in the corridor under the conditions of the corridor experiments described in this report.

2. Temperature data and profiles do not appear to show significant difference in performance of the various underlayments.

3. The proposed flooring radiant panel test demonstrated the insulating effect of the underlayment on the extent of burning. All of the underlayments lowered the critical radiant flux compared to the carpet alone.

4. High concentrations of toxic combustion products such as HCN and CO, were observed at the time of flashover with both cellulosic and synthetic underlayments. However, prior to flashover, and in those cases where flashover did not occur, there was no significant buildup of toxic gases. No attempt was made to correlate these measurements with animal exposure.

5. All of the underlayments, used in combination with a standard carpet, had a higher maximum specific optical density in the smoldering mode when tested according to NFPA 258T than the carpet alone. In the flaming mode, however, the smoke values from the carpet and the carpet plus the underlayment are similar. The exception is the integral pad system which had a higher smoke value in the smoldering or the flaming than any of the others.

6. ACKNOWLEDGMENTS

The author gratefully acknowledges partial funding for this project by the Urethane Foam Safety Group of the Society of the Plastics Industries.

7. REFERENCES

[1] Fung, F. C. W., Suchomel, M. R. and Oglesby, P. L., The NBS Program on Corridor Fires, Fire Journal, Vol. 67, 41 (1973).

[2] Huggett, C., Carpet Flammability and the NBS Corridor Fire Program, ASTM Standardization News, Vol. 1, 16 (1973).

[3] Christian, W. J. and Waterman, T. E., Fire Behavior of Interior Finish Materials, Fire Technology (Aug. 1970).

[4] Leithe, W., The Analysis of Air Pollutants, 227 (1970 ed.)

[5] Christian, W. J. and Waterman, T. E., Characteristics of Full-Scale Fires in Various Occupancies, Fire Technology (Feb. 1971).

[6] Quintiere, J., Some Observations on Building Corridor Fires, Fifteenth Symposium (International) on Combustion, held in Tokyo, Japan on August 25-31, 1974.

[7] Fournier, L. B., Standard Methods of Analysis of Water and Waste Water, and ASTM Methods, 14th Edition.

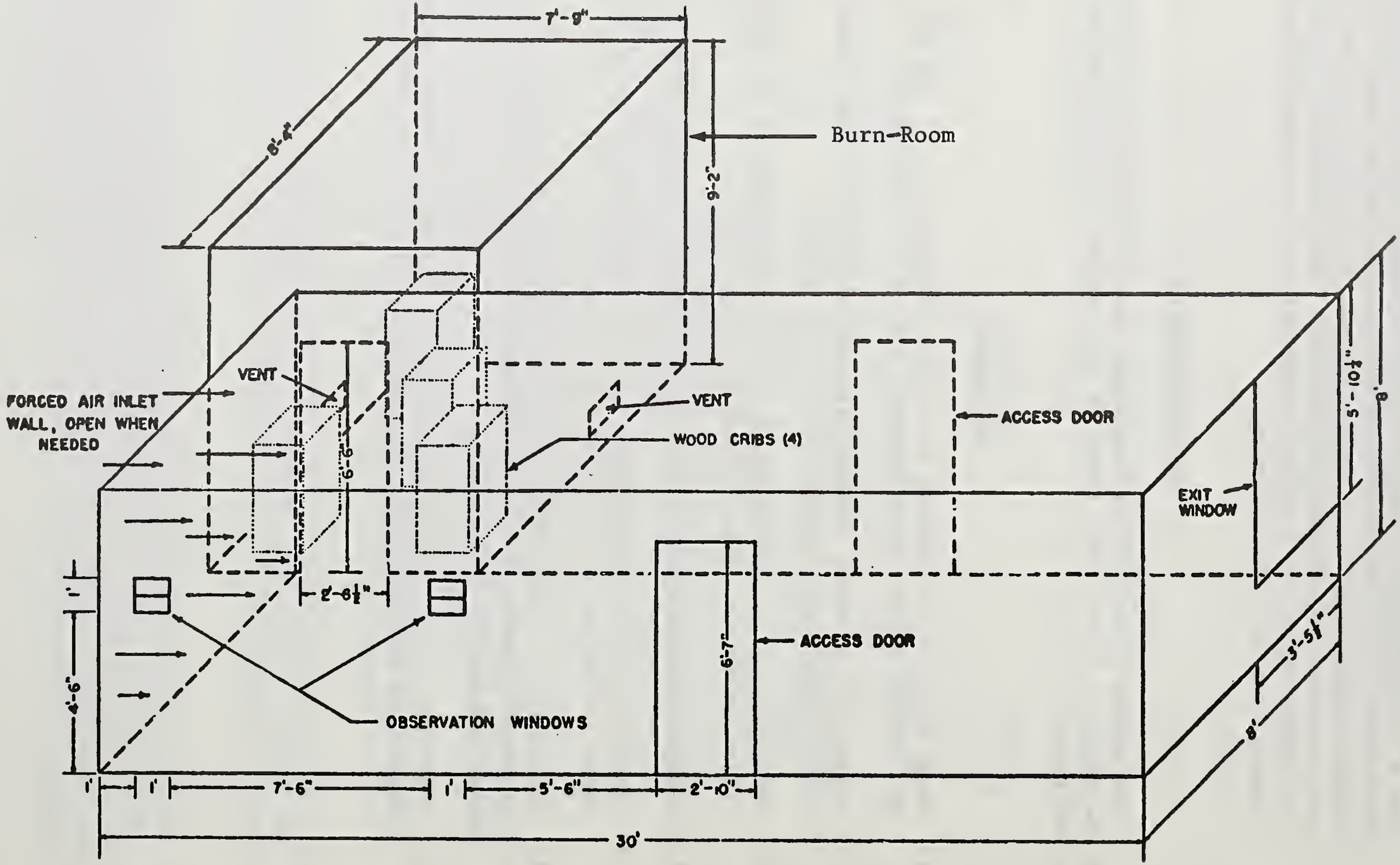

Figure 1. Corridor Facility

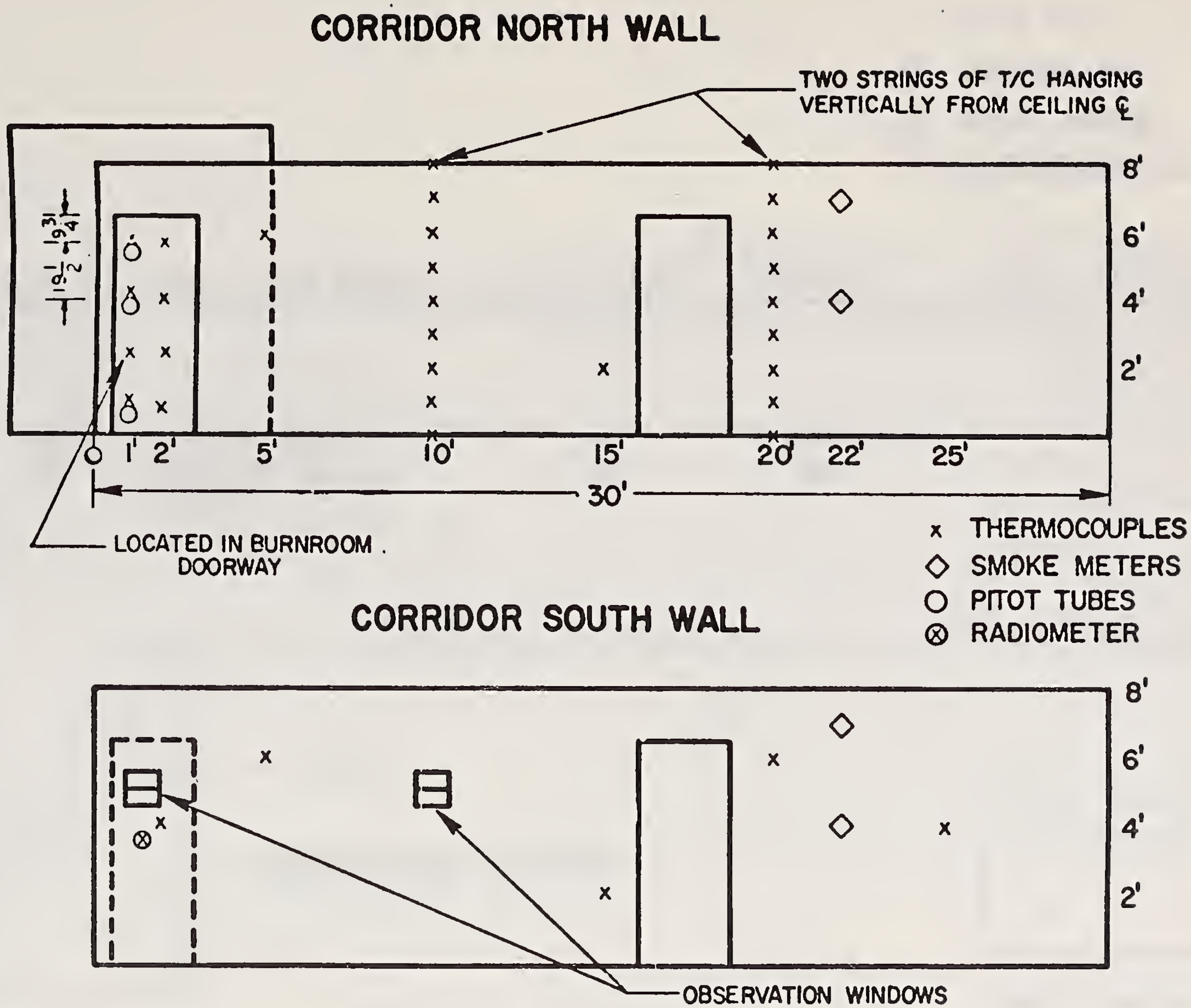

Figure 2. Corridor Wall Sensor Locations

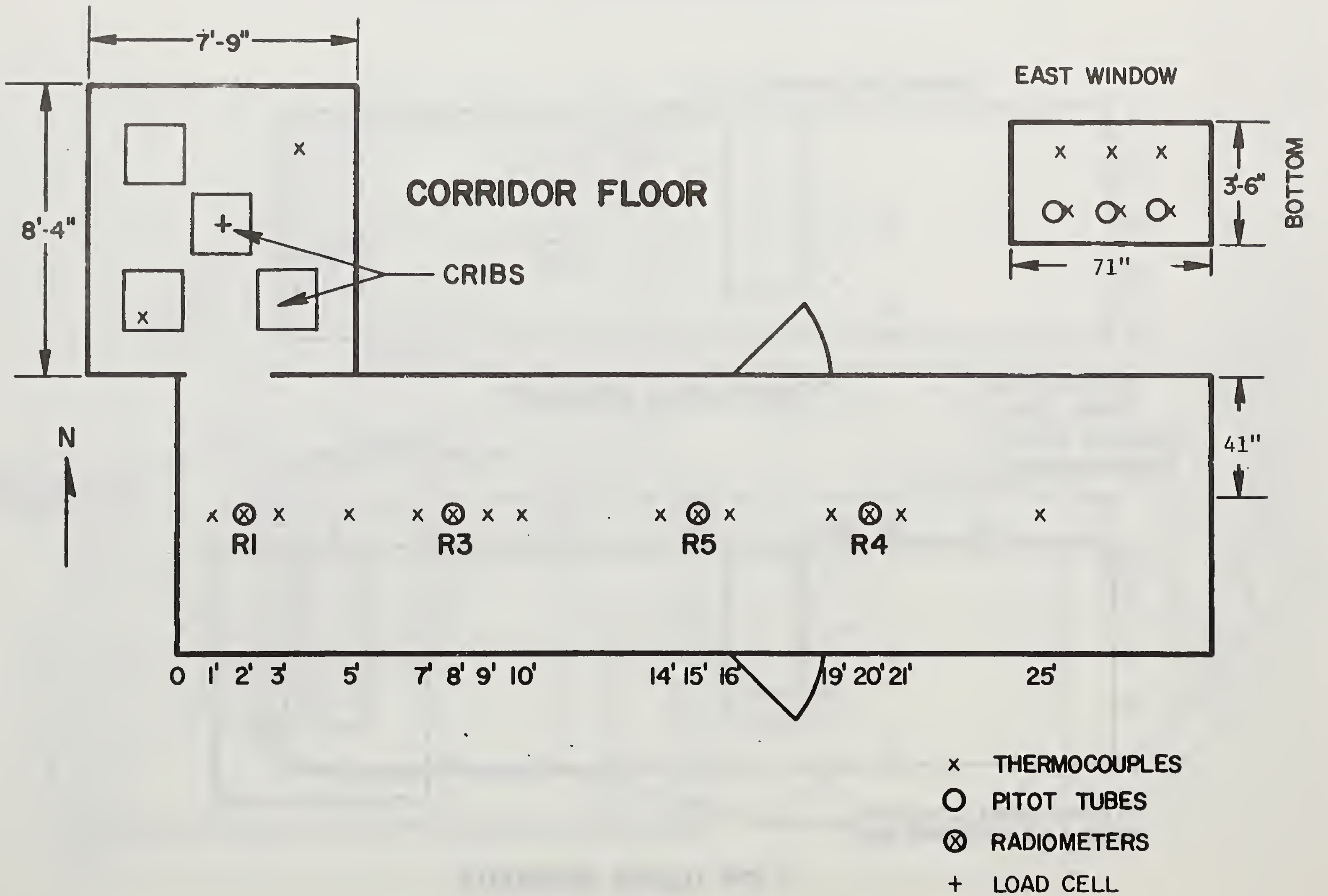

Figure 3. Corridor Floor Sensor Locations

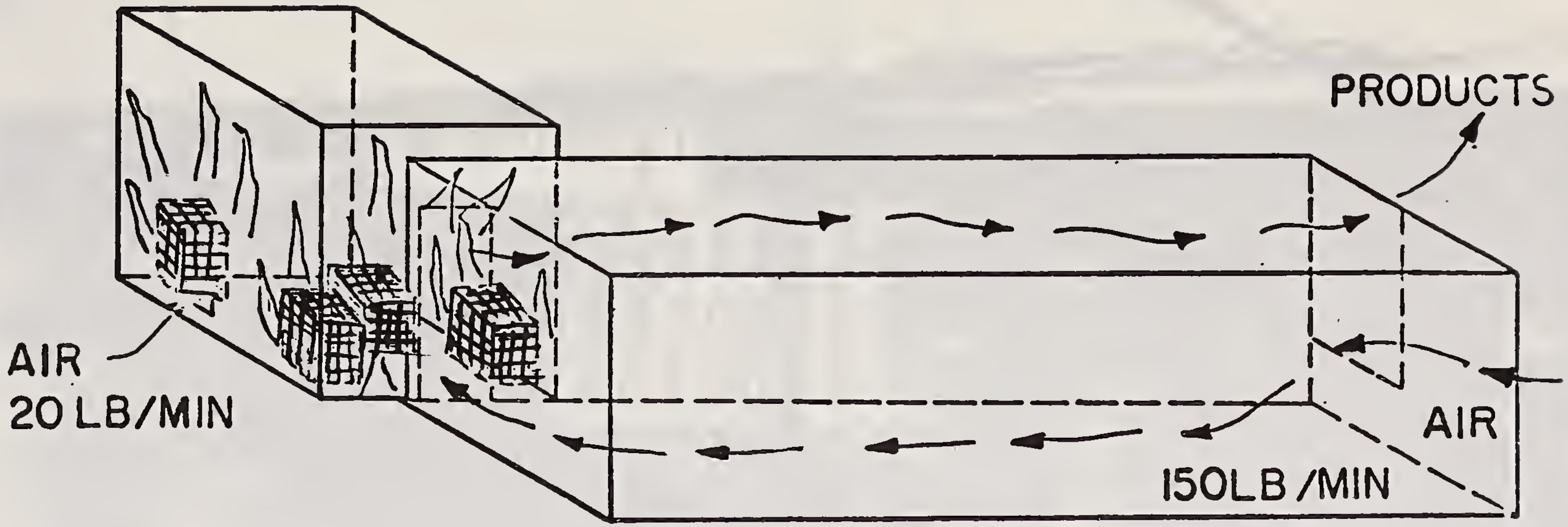

Figure 4. Burning Mode in Corridor.

Figure 5. View in Corridor Fire Room Door Showing Wood Cribs. Center Crib on Load Cell. Thermocouples and Pitot Tubes in Doorway.

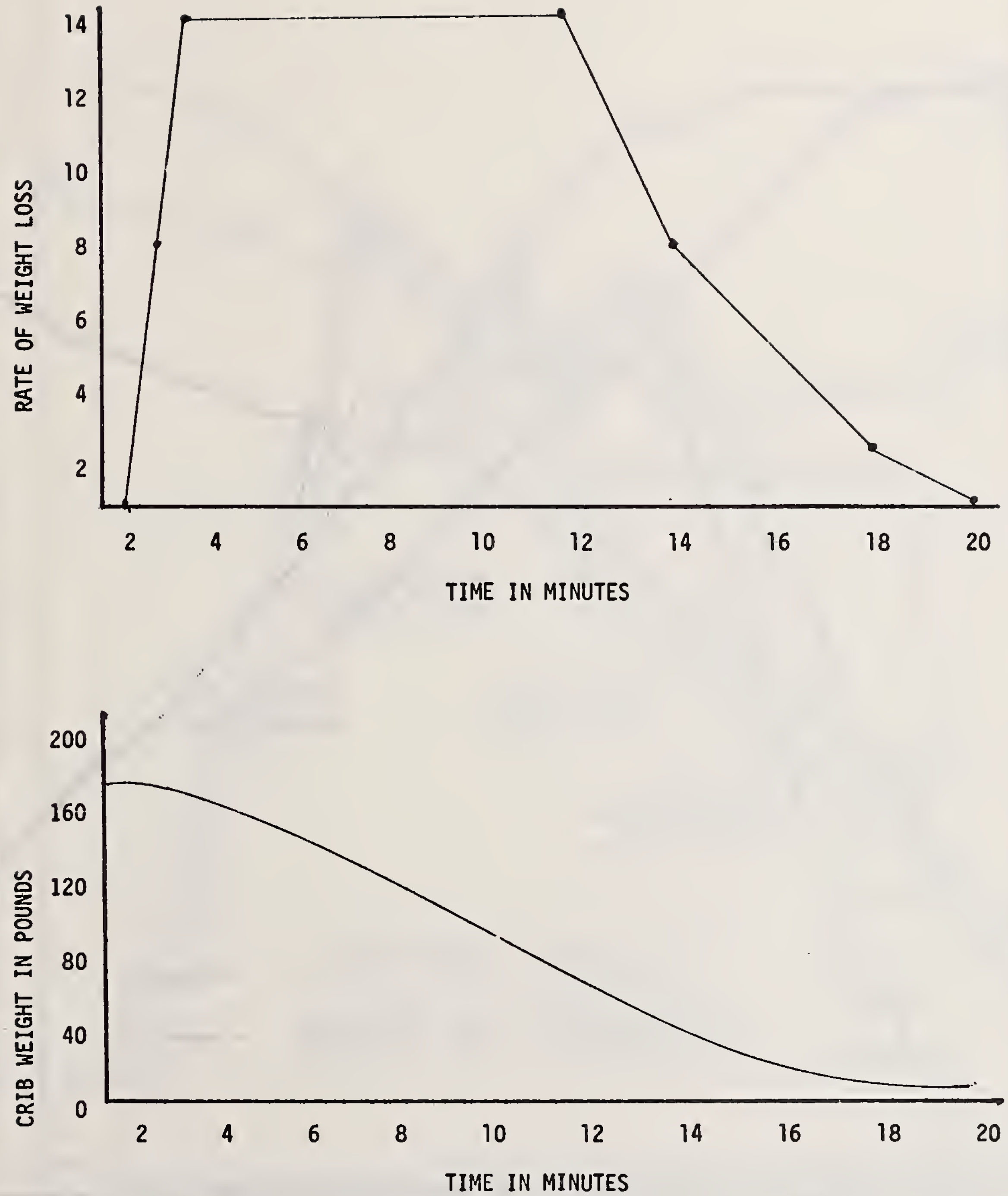

Figure 6. Weight Loss Derived from Load Cell Data

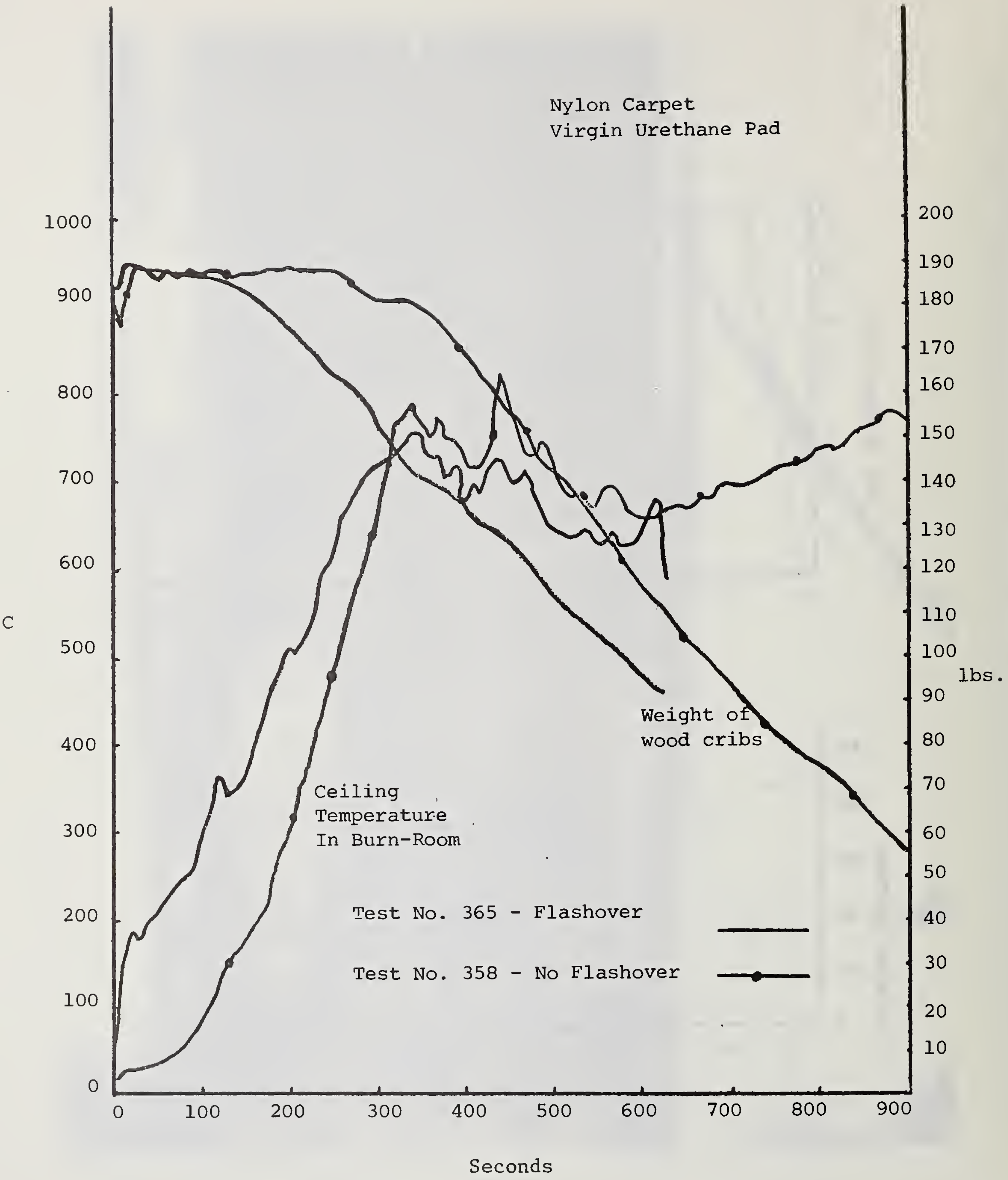

Figure 7. Ceiling Temperature and Weight Loss of Cribs in Burn-Room.

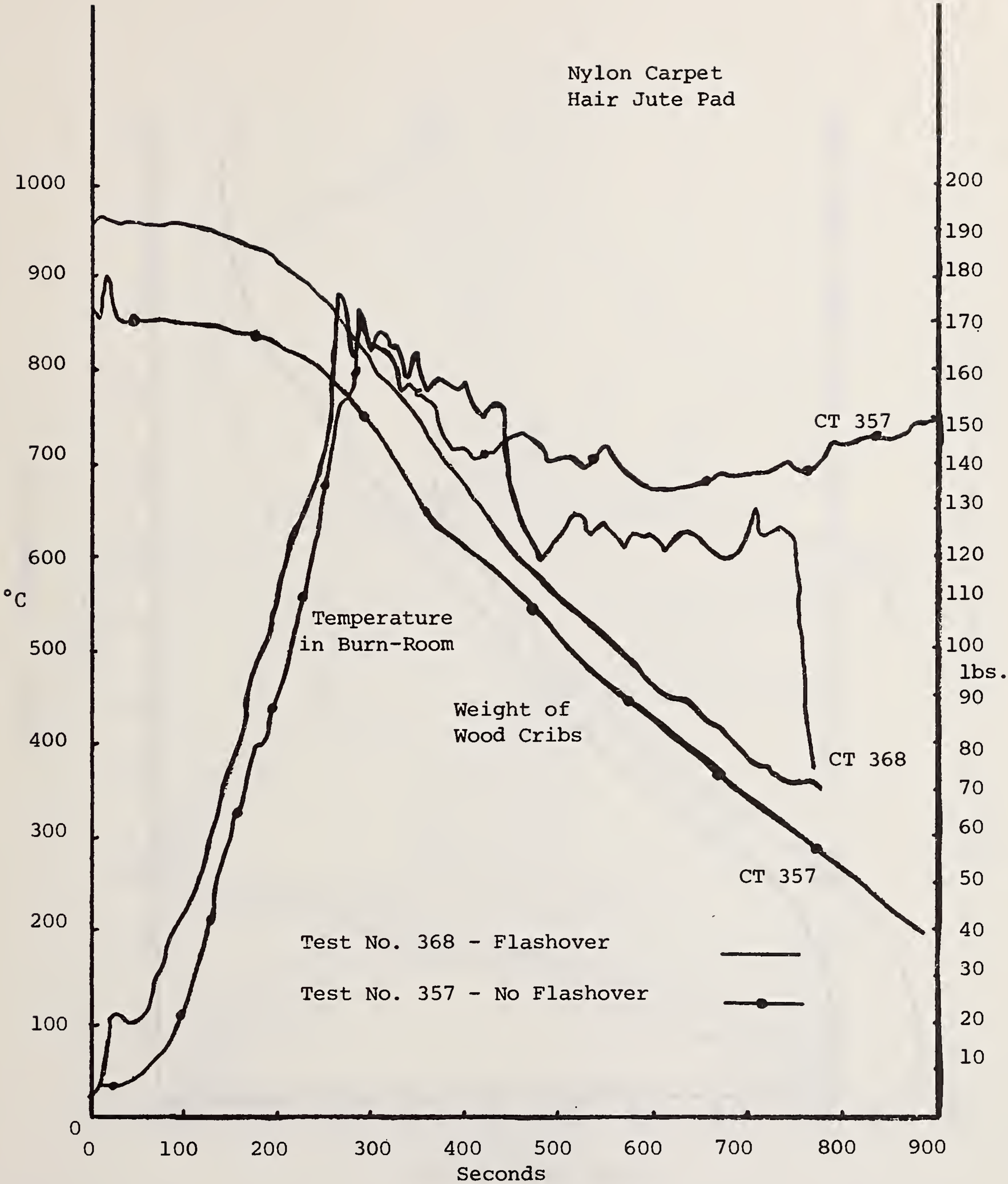

Figure 8. Ceiling Temperature and Weight Loss of Cribs in Burn-Room

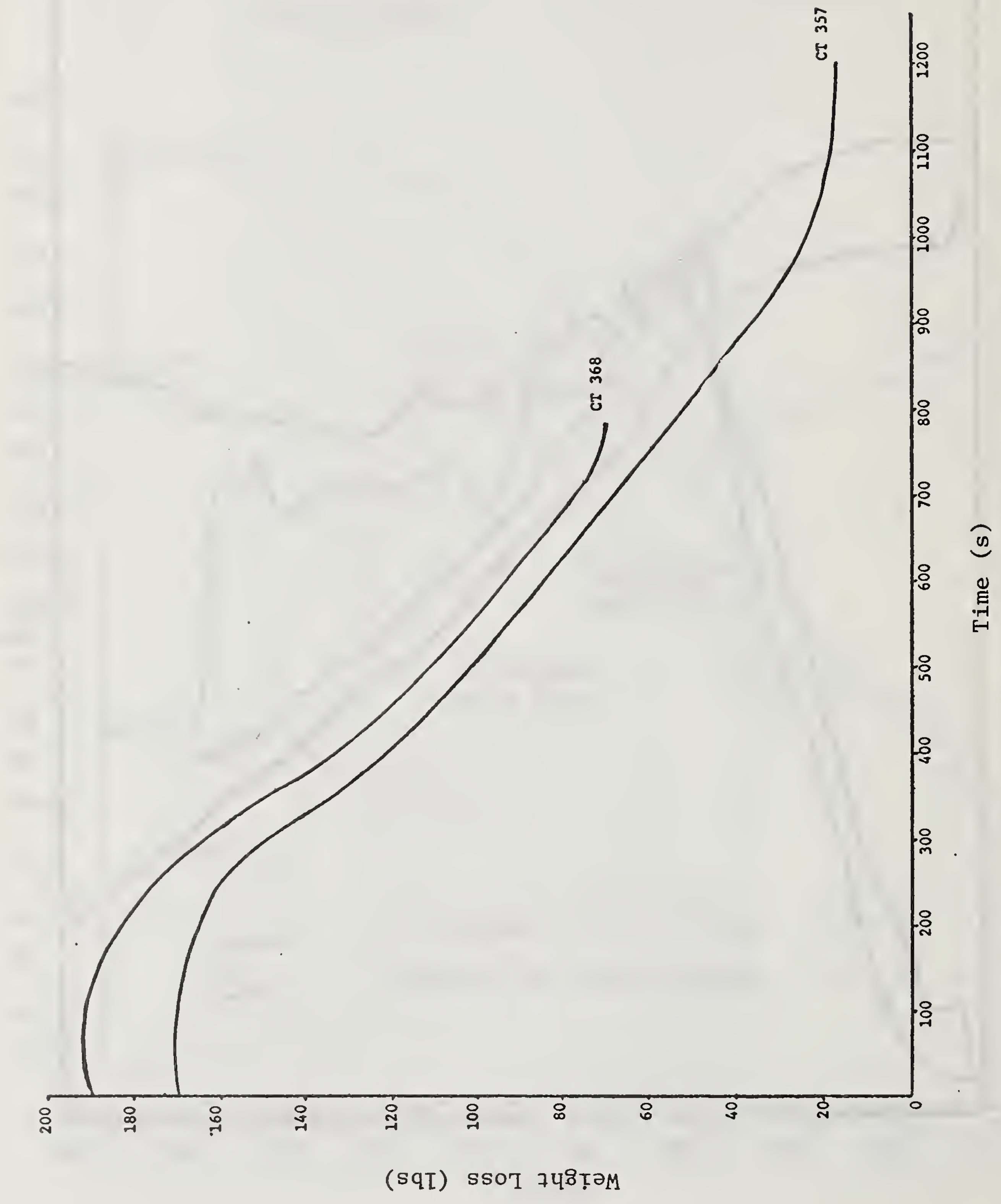

Figure 9. Weight Loss

Figure 10. TC Center of Burn-Room Ceiling

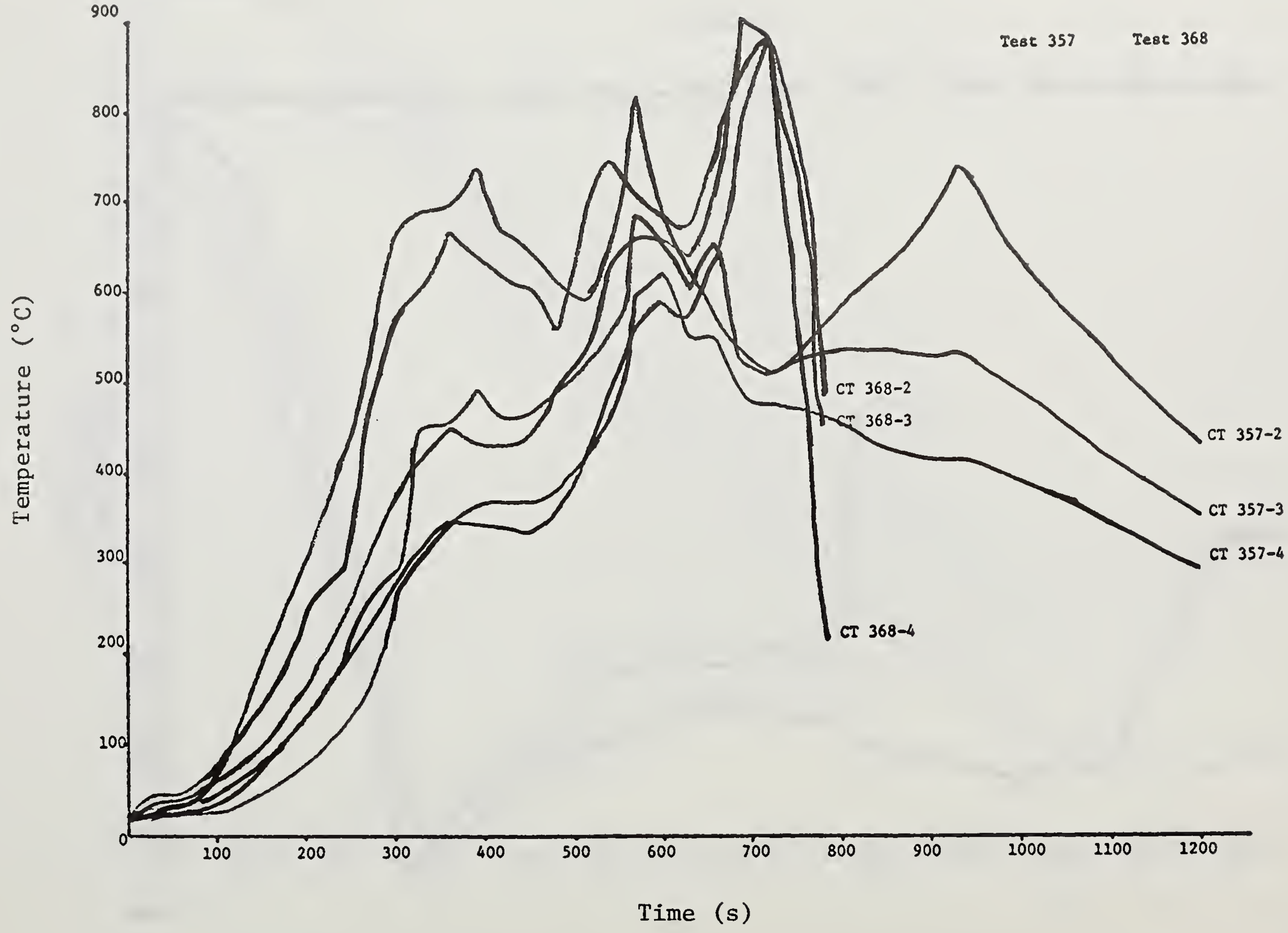

Figure 11. TC String Corridor CL Ceiling

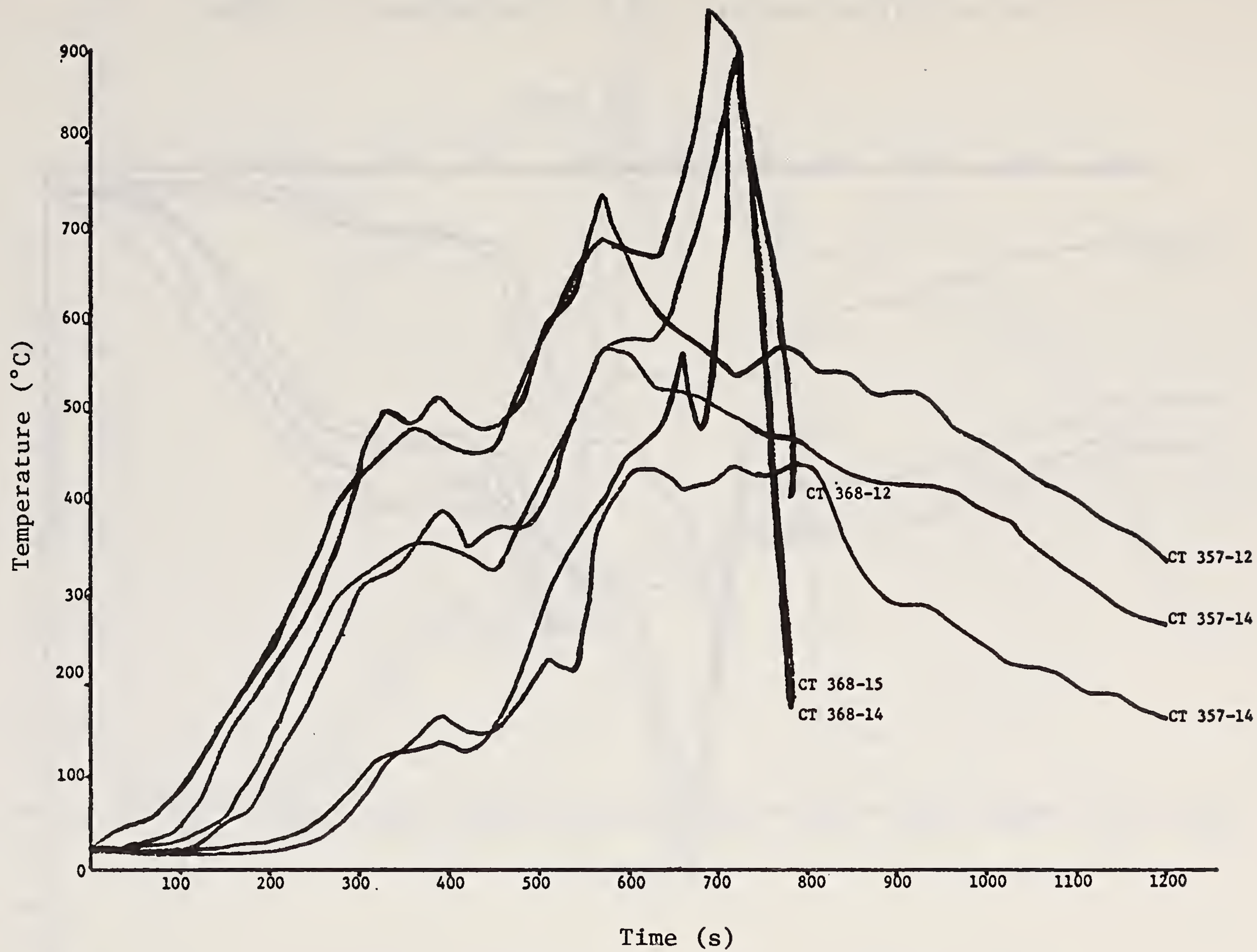

Figure 12. Temperature 12-14-15, 5 ft String 1, 3 and 5 ft from Ceiling

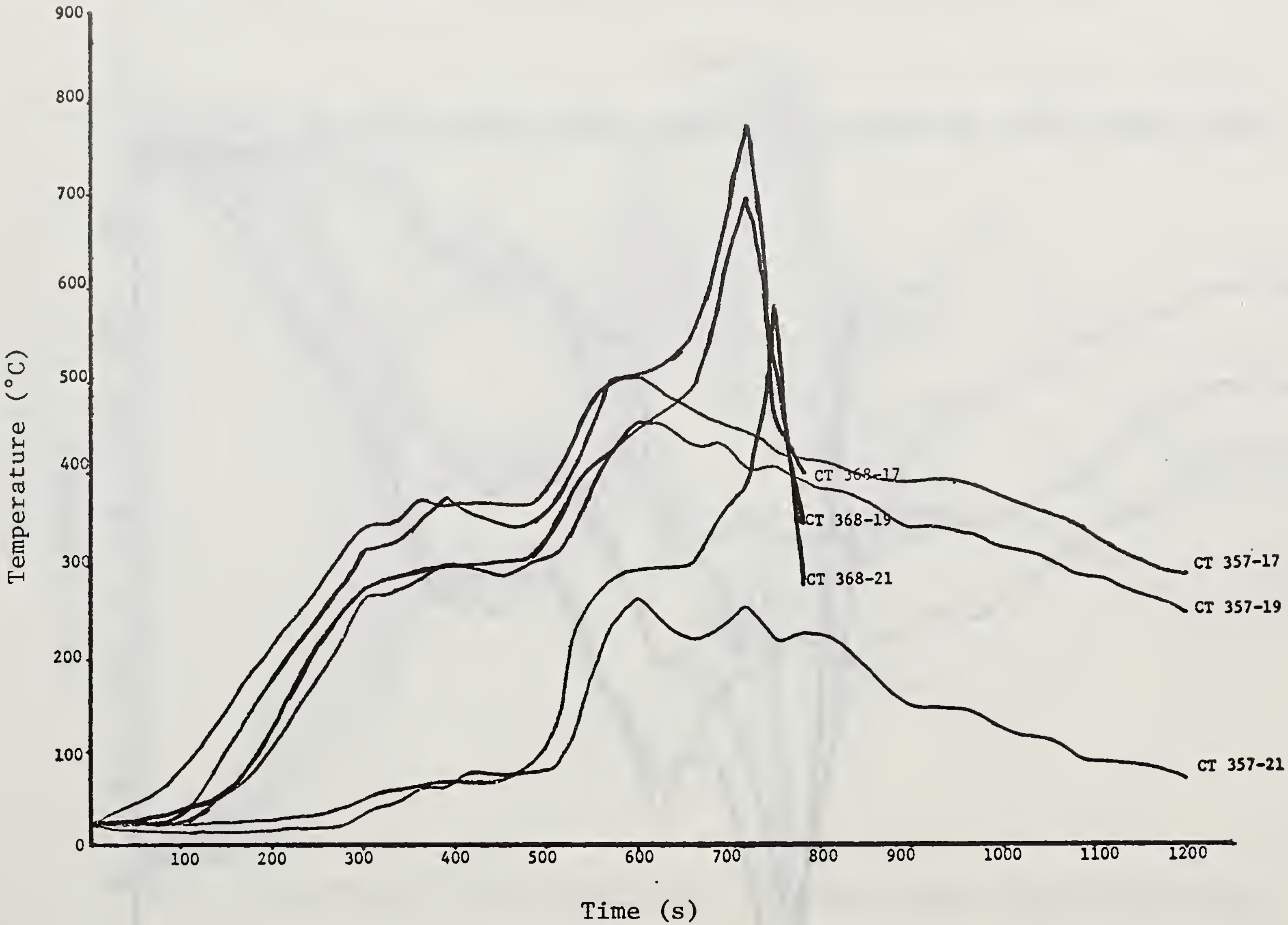

Figure 13. Temperature 1, 3 and 5 ft from ceiling at 25 ft

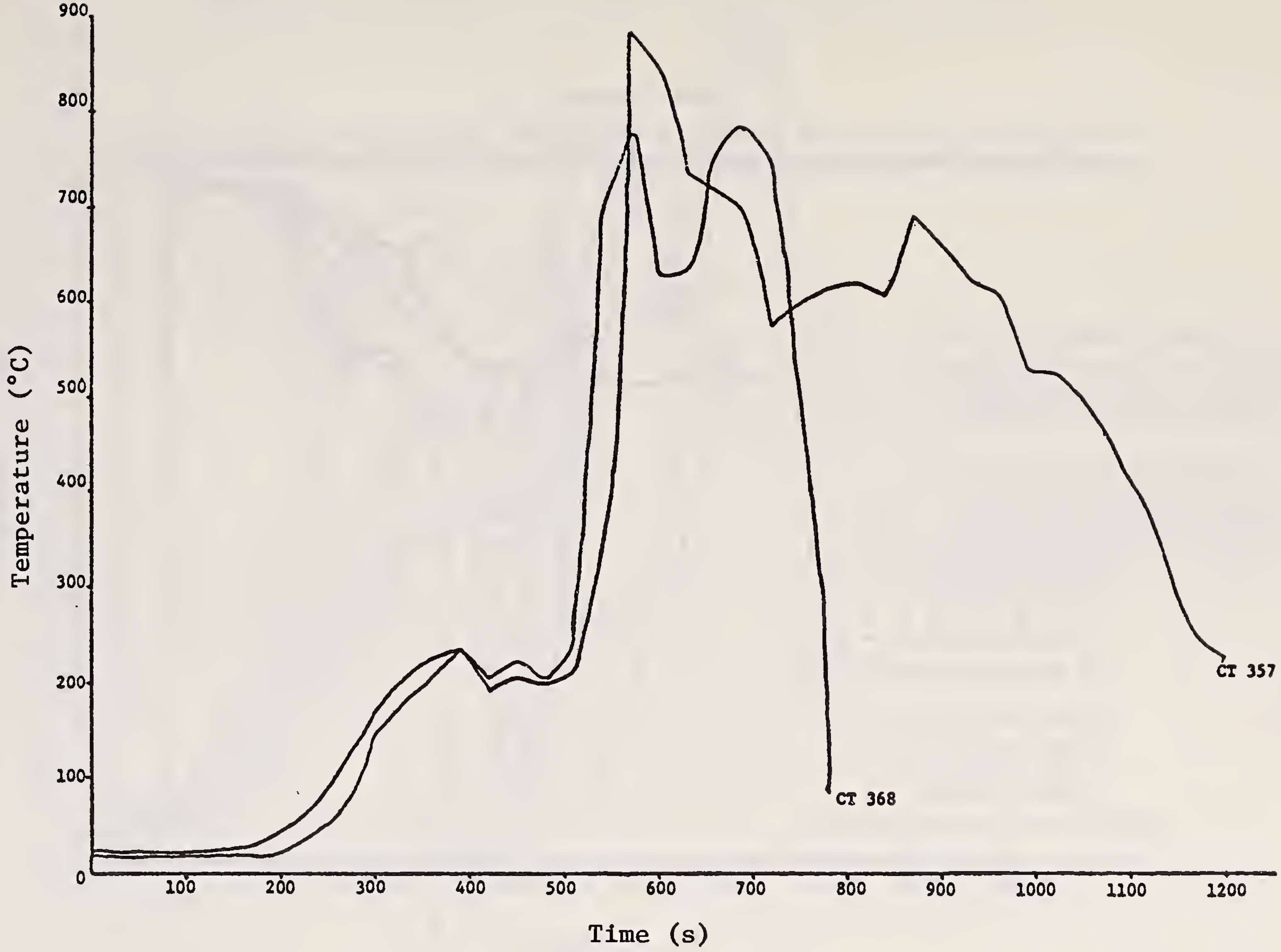

Figure 14. Temperature TC 5 ft from West Wall

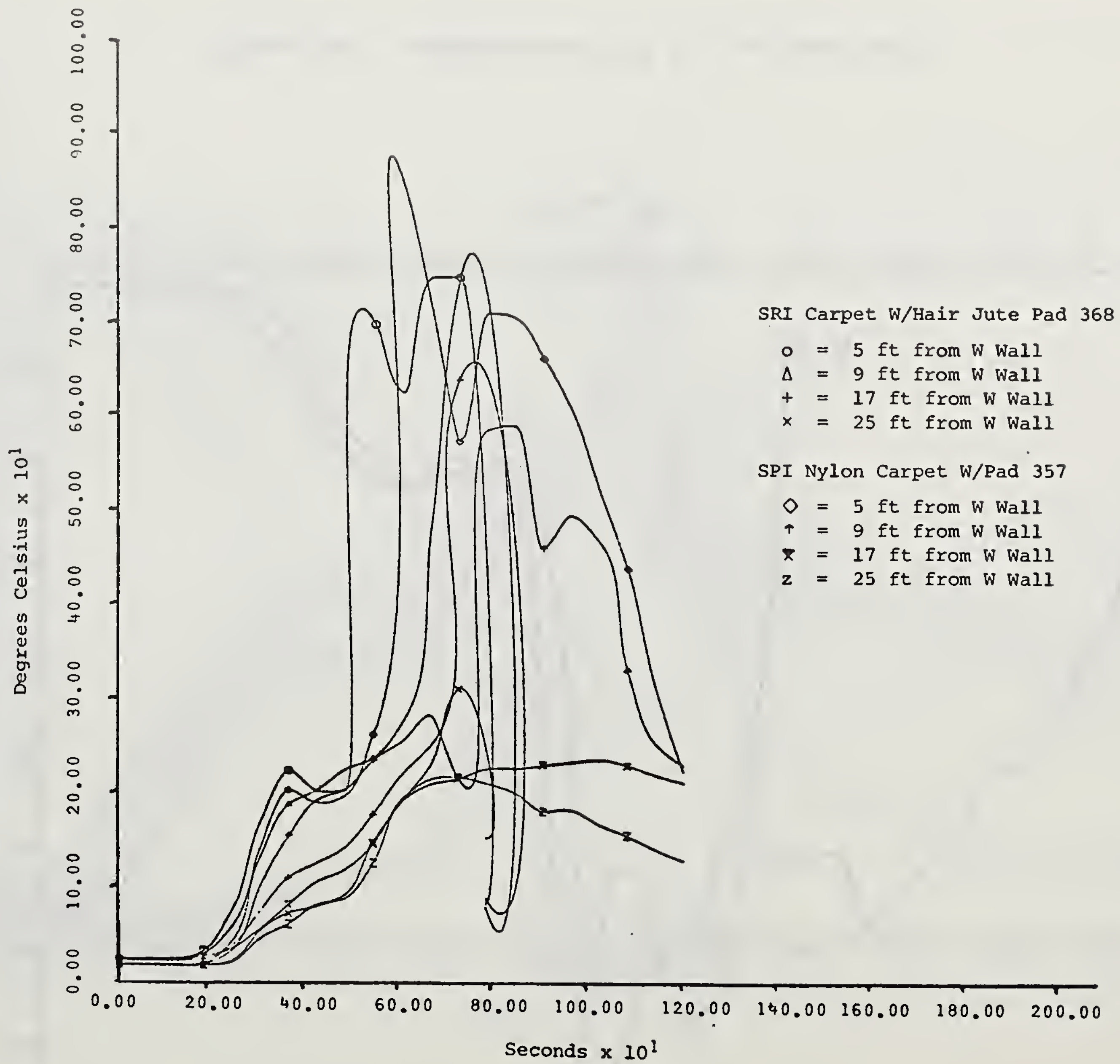

Figure 15. Temperature Profile — Center Line of Floor

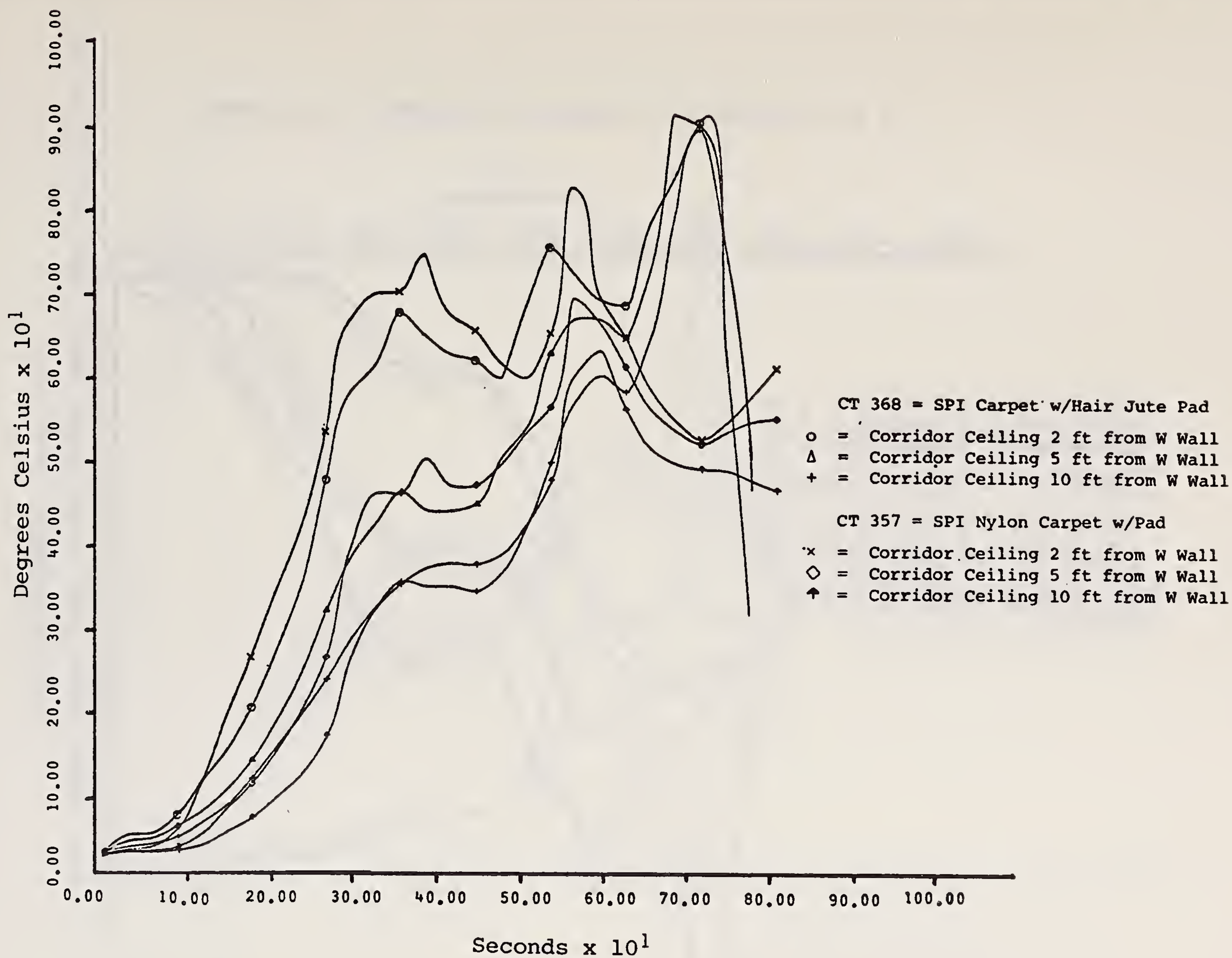

Figure 16. Temperature Profile — Corridor Ceiling

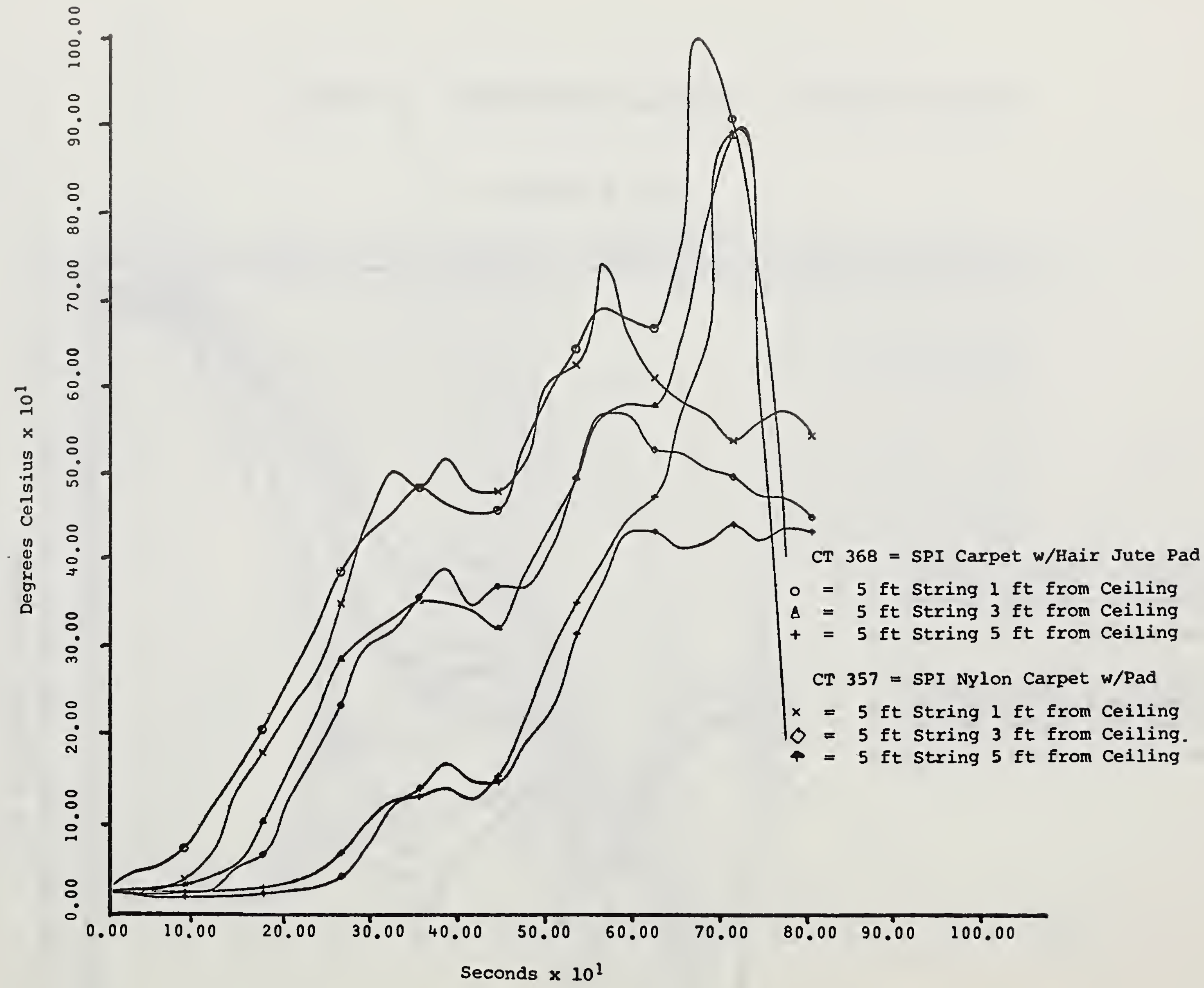

Figure 17. Temperature Profile — Corridor at 5 ft

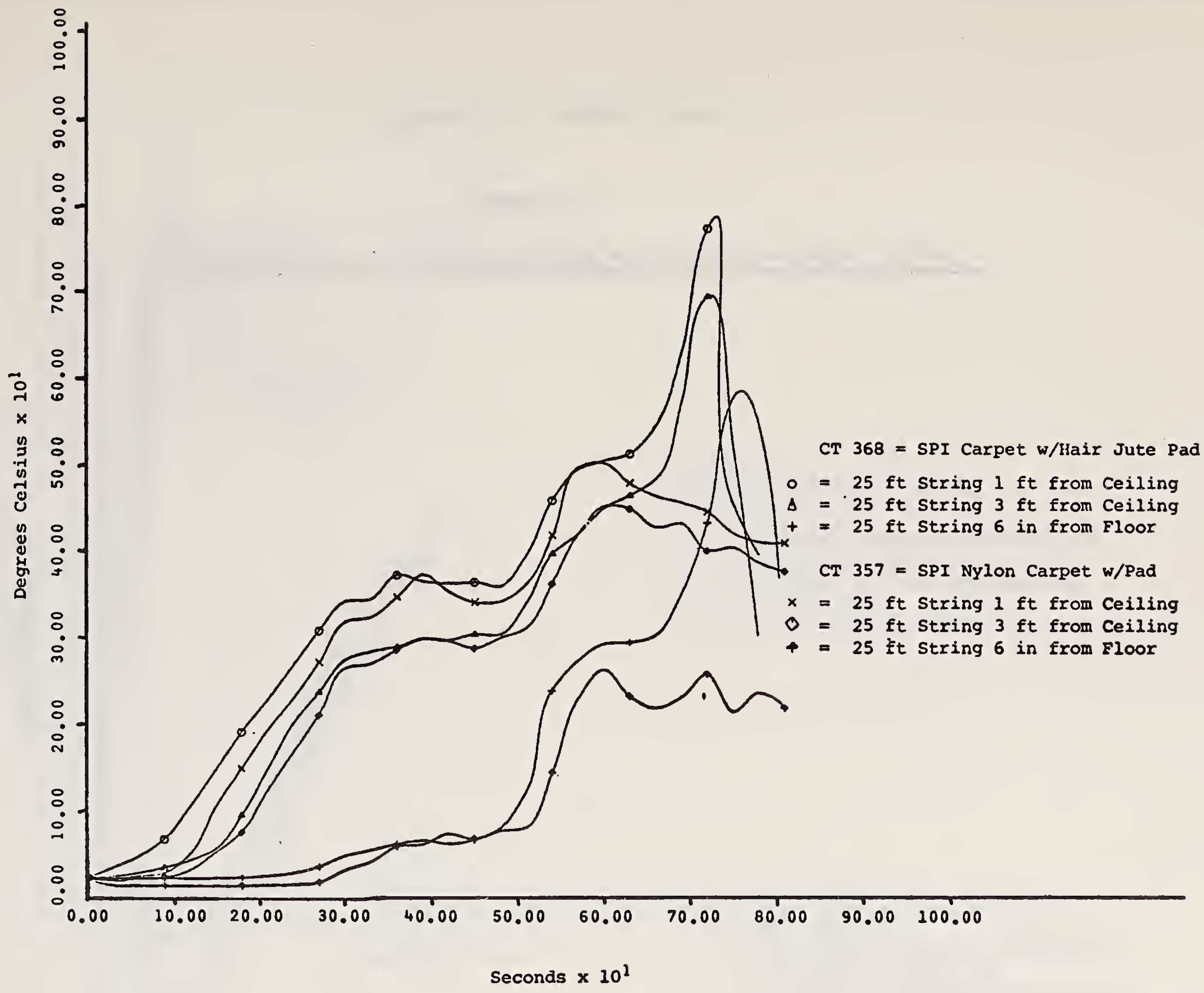

Figure 18. Temperature Profile — Corridor at 25 ft

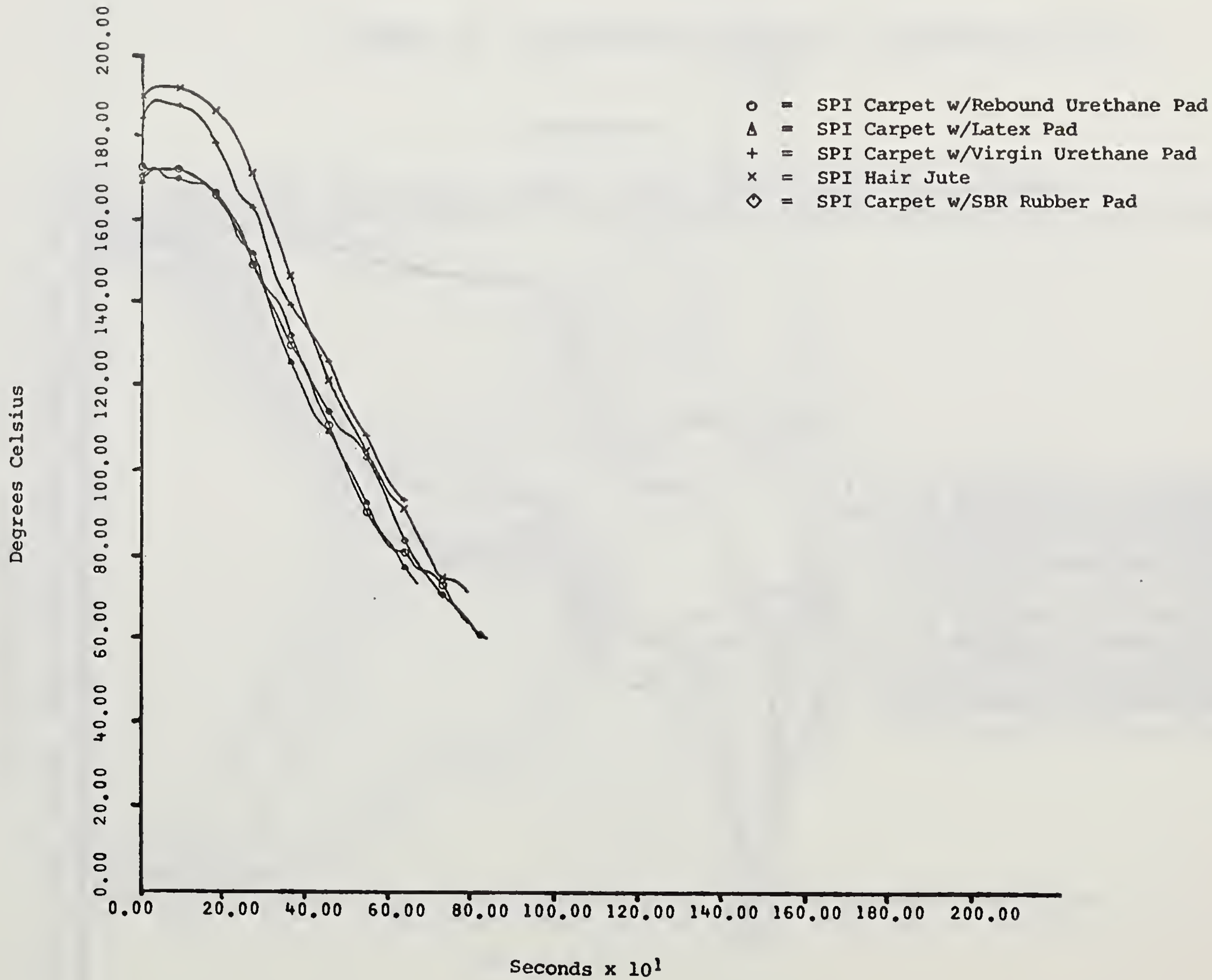

Figure 19. Weight Loss

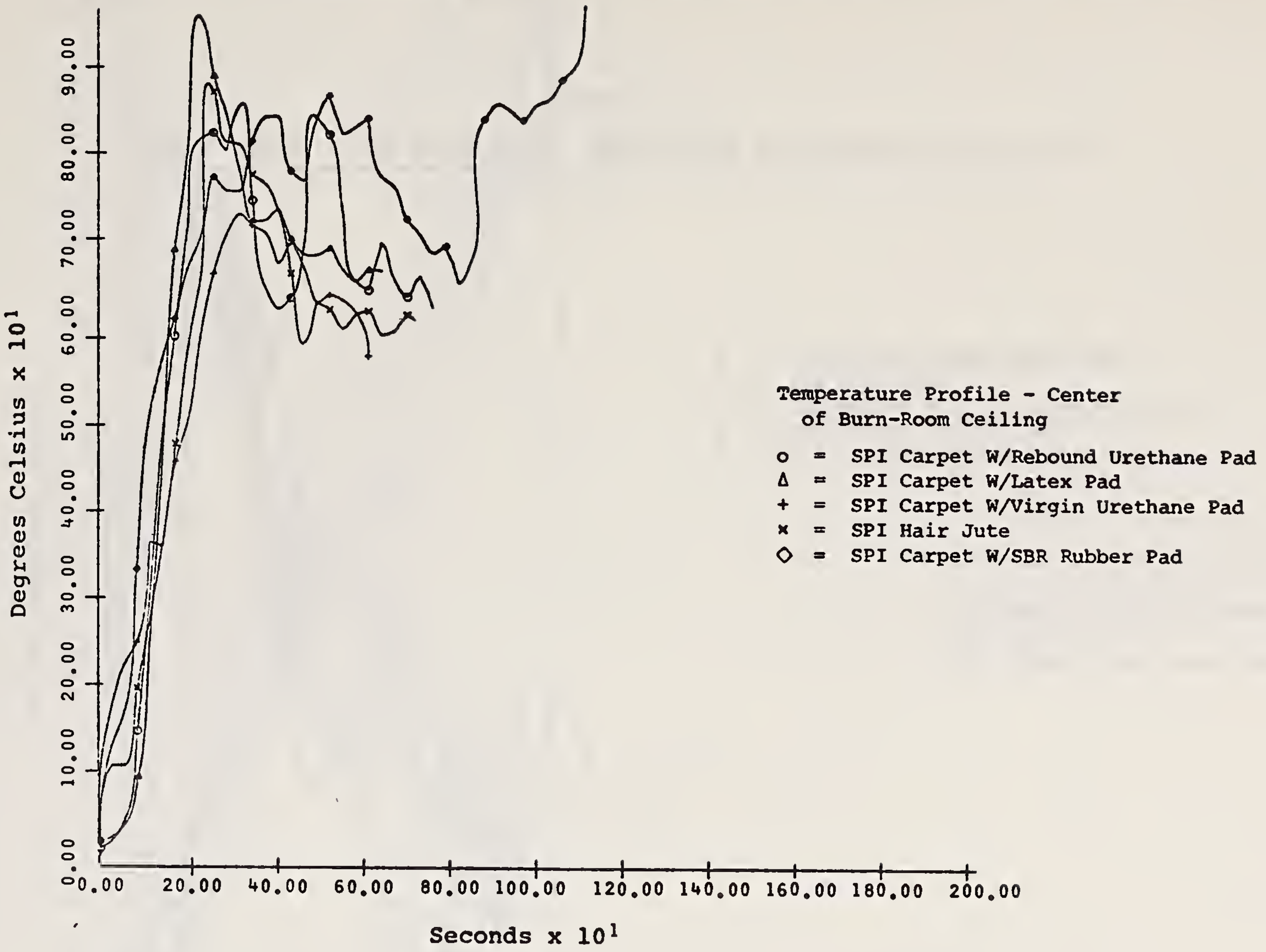

Figure 20. Temperature Profile — Center of Burn-Room Ceiling

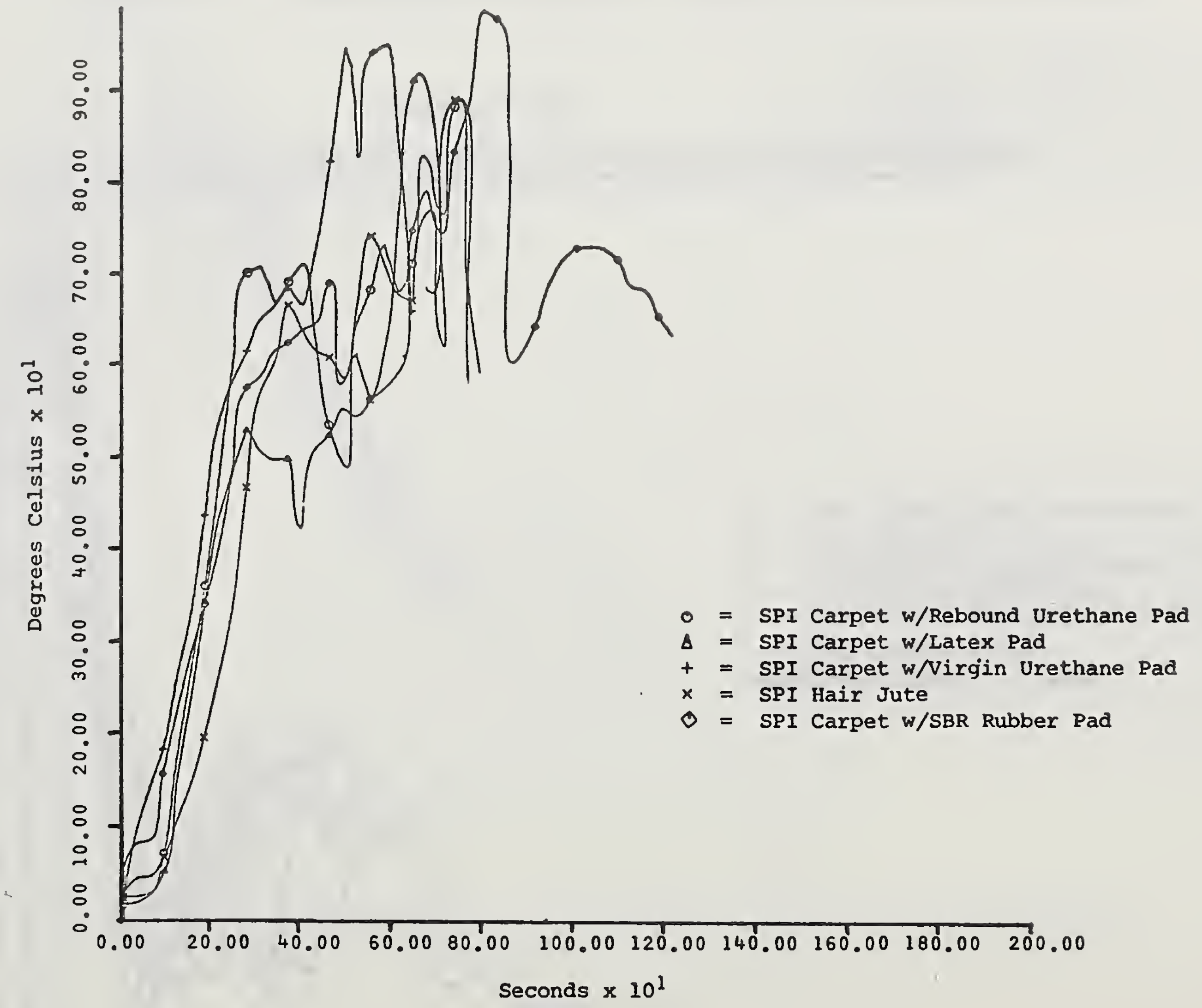

Figure 21. Temperature Profile — Corridor Ceiling 2 ft from West Wall

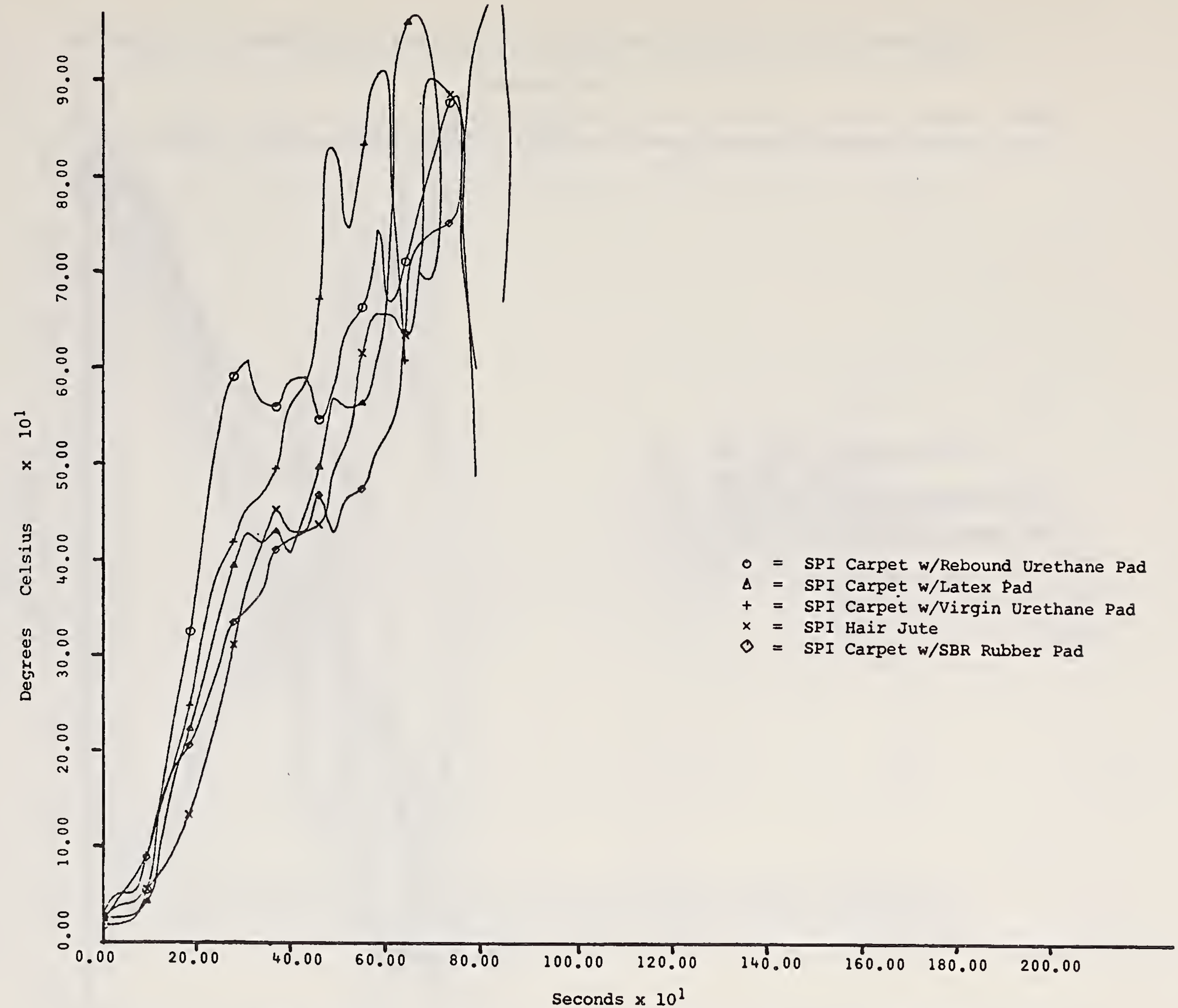

Figure 22. Temperature Profile — Corridor Ceiling 5 ft from West Wall

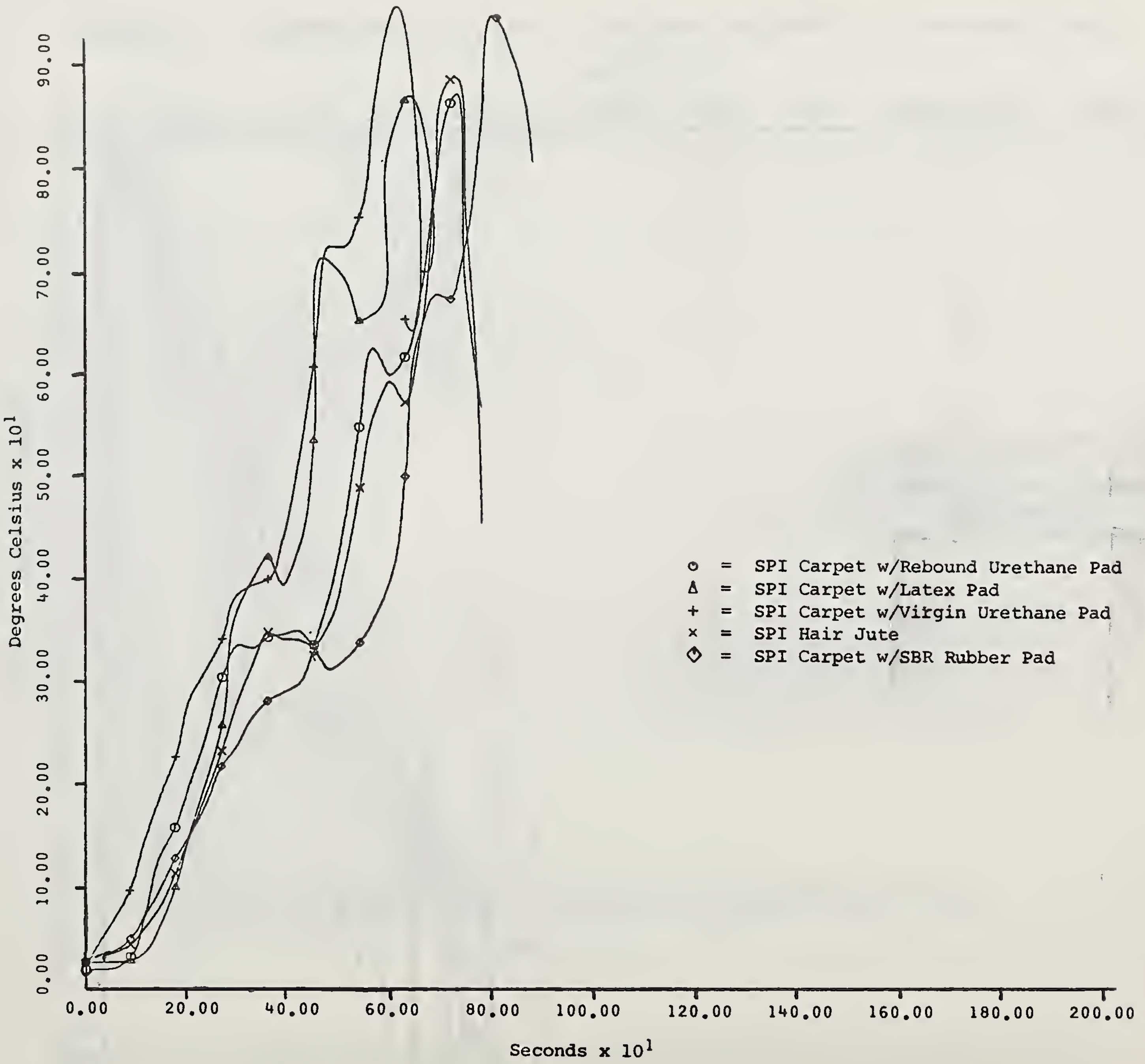

Figure 23. Temperature Profile — Corridor Ceiling 10 ft from Wall

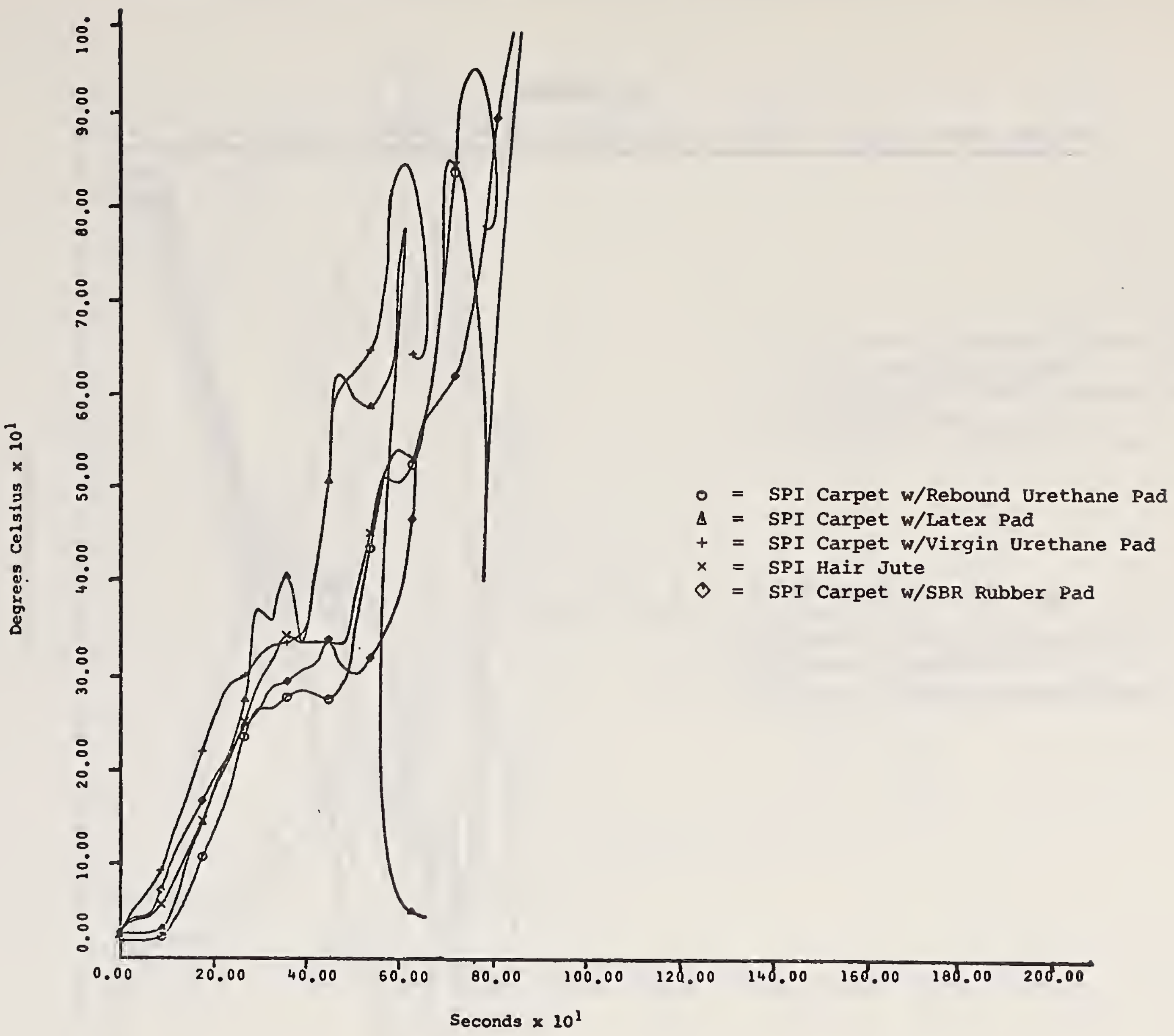

Figure 24. Temperature Profile — Corridor Ceiling 15 ft from West Wall

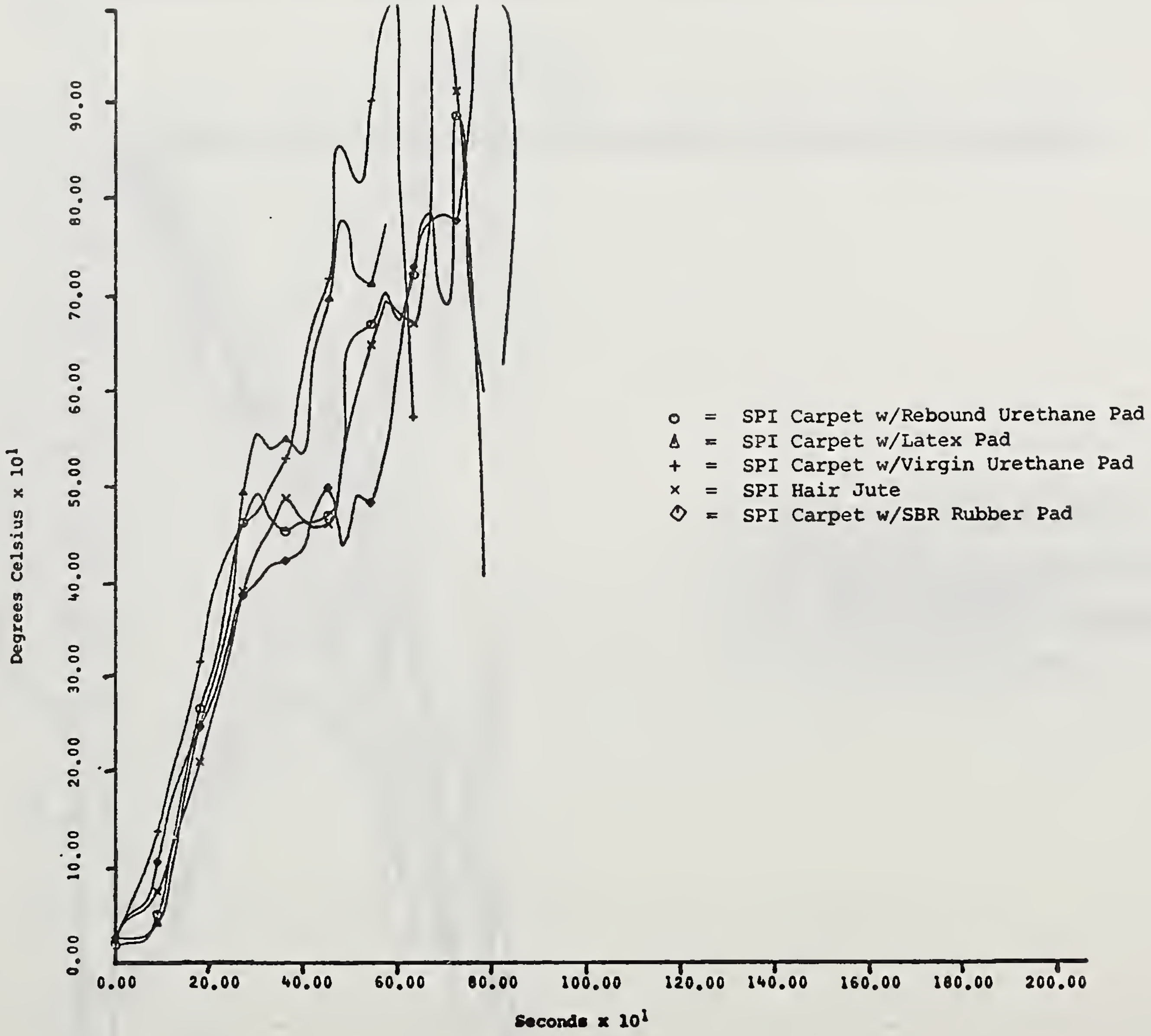

Figure 25. Temperature Profile — 5 ft String 1 ft from Ceiling

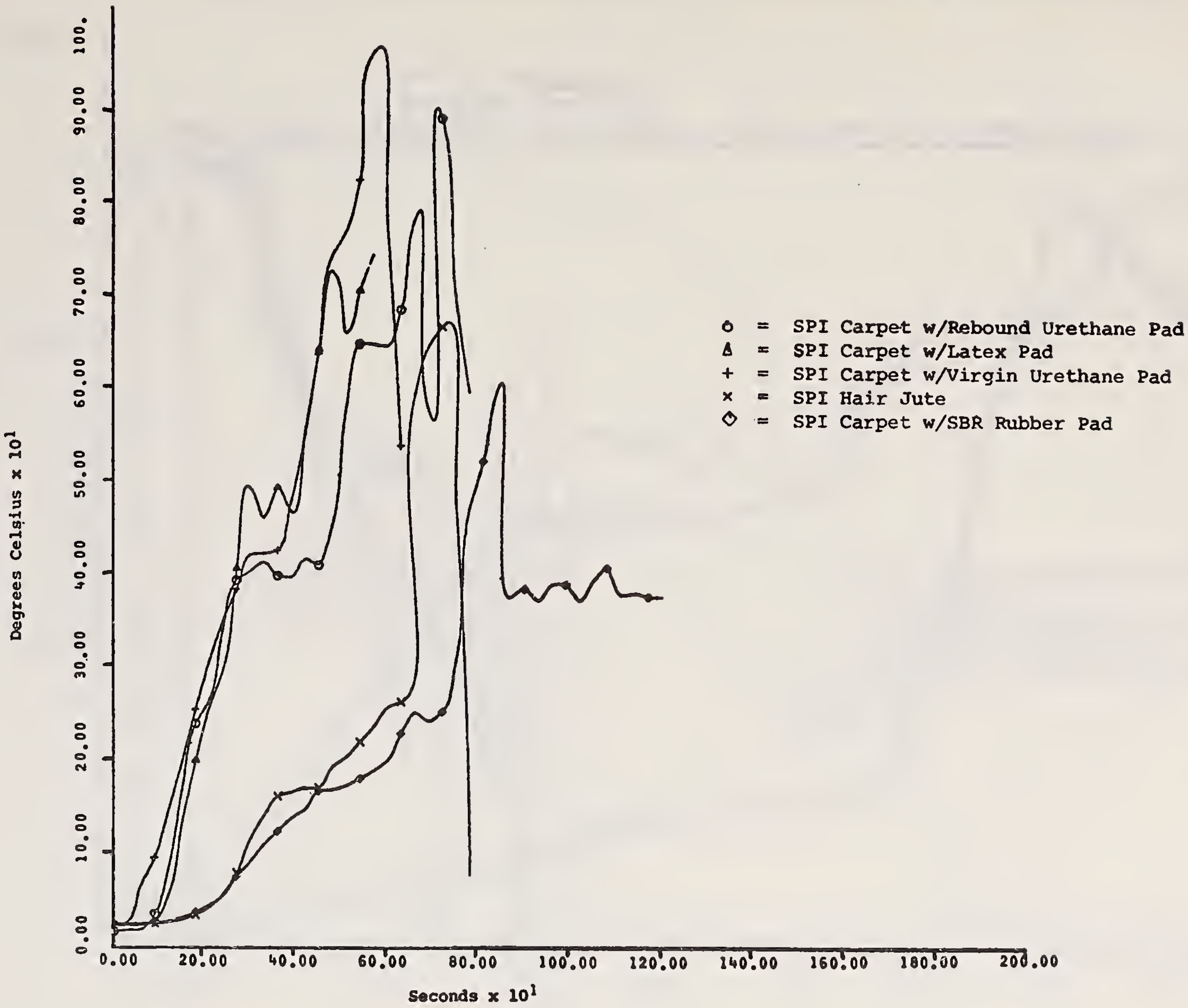

Figure 26. Temperature Profile — 5 ft String 2 ft from Ceiling

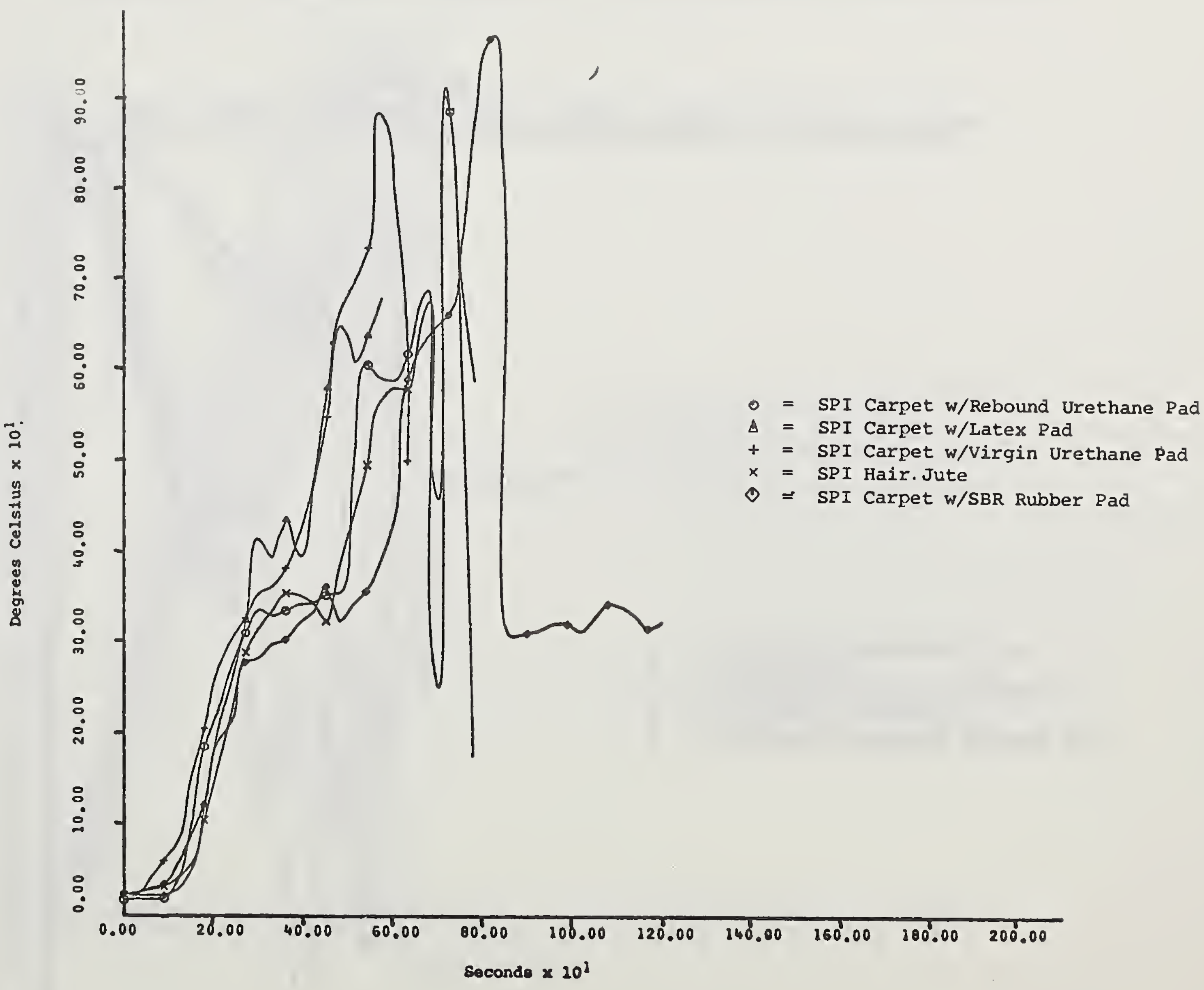

Figure 27. Temperature Profile — 5 ft String 3 ft from Ceiling

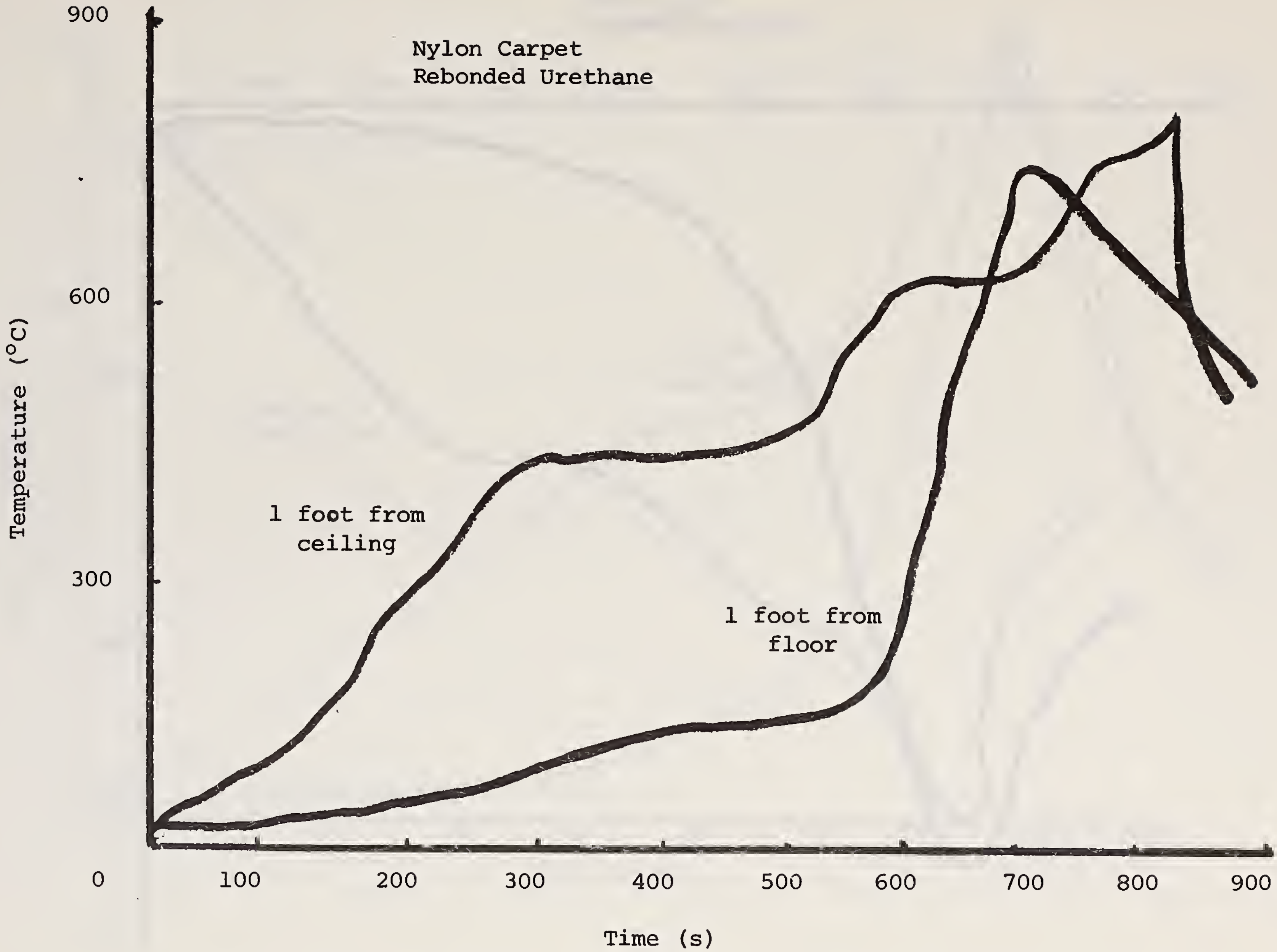

Figure 28. Test No. 361 — Temperature at Center 5 ft down Corridor

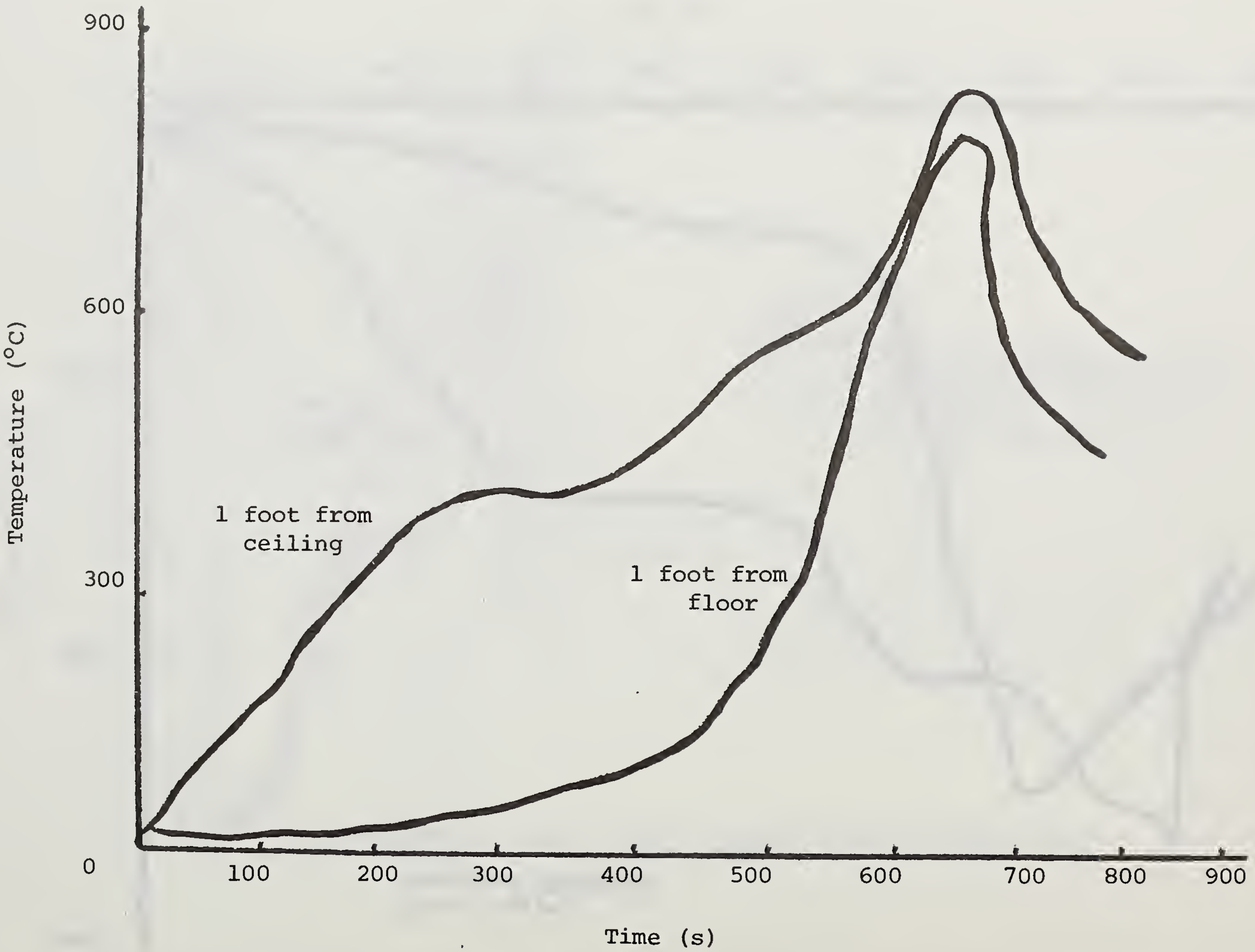

Figure 29. Test No. 357 — Temperature at Center 5 ft down Corridor

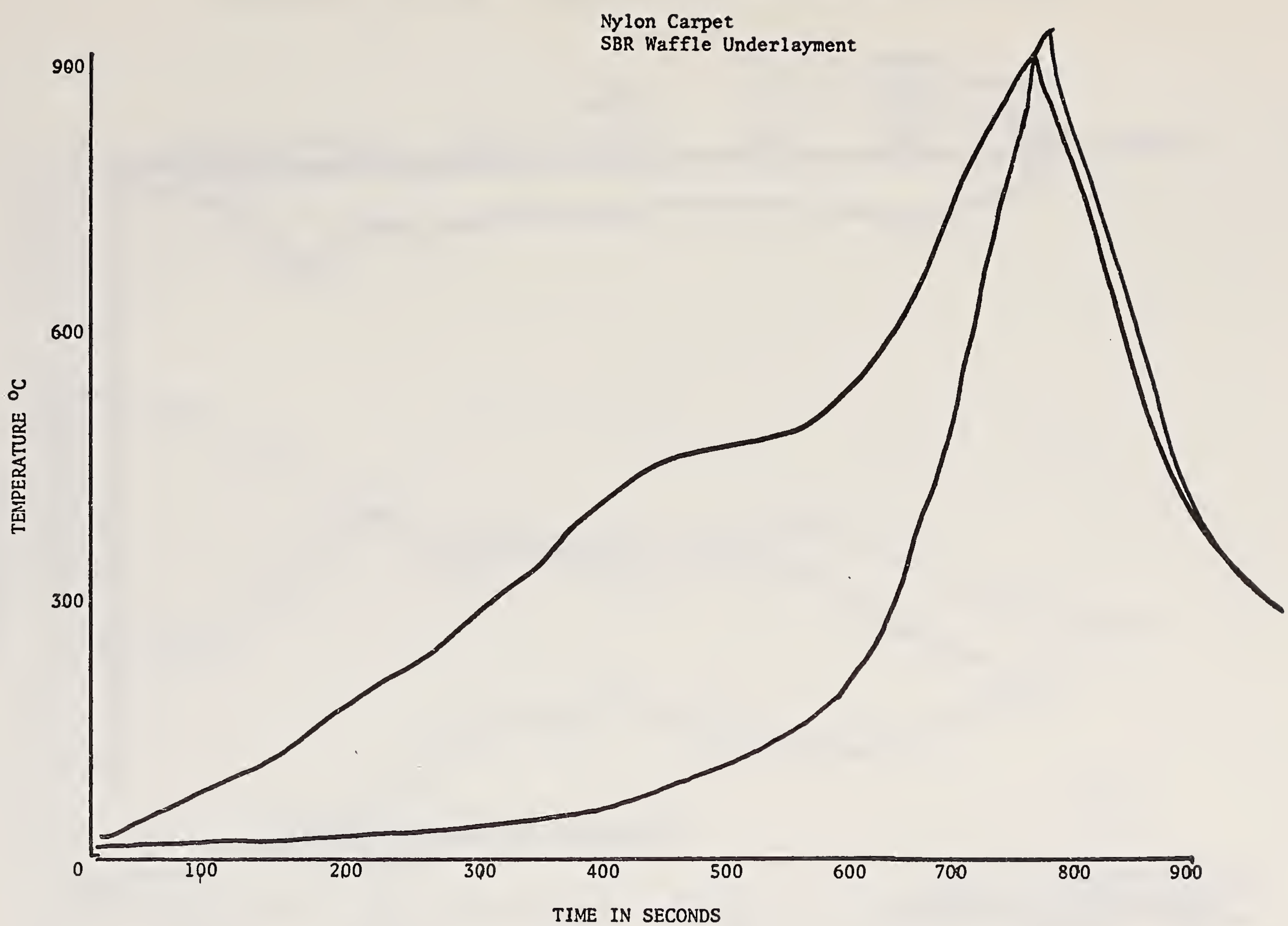

Figure 30. Temperature at Center 5 ft down Corridor

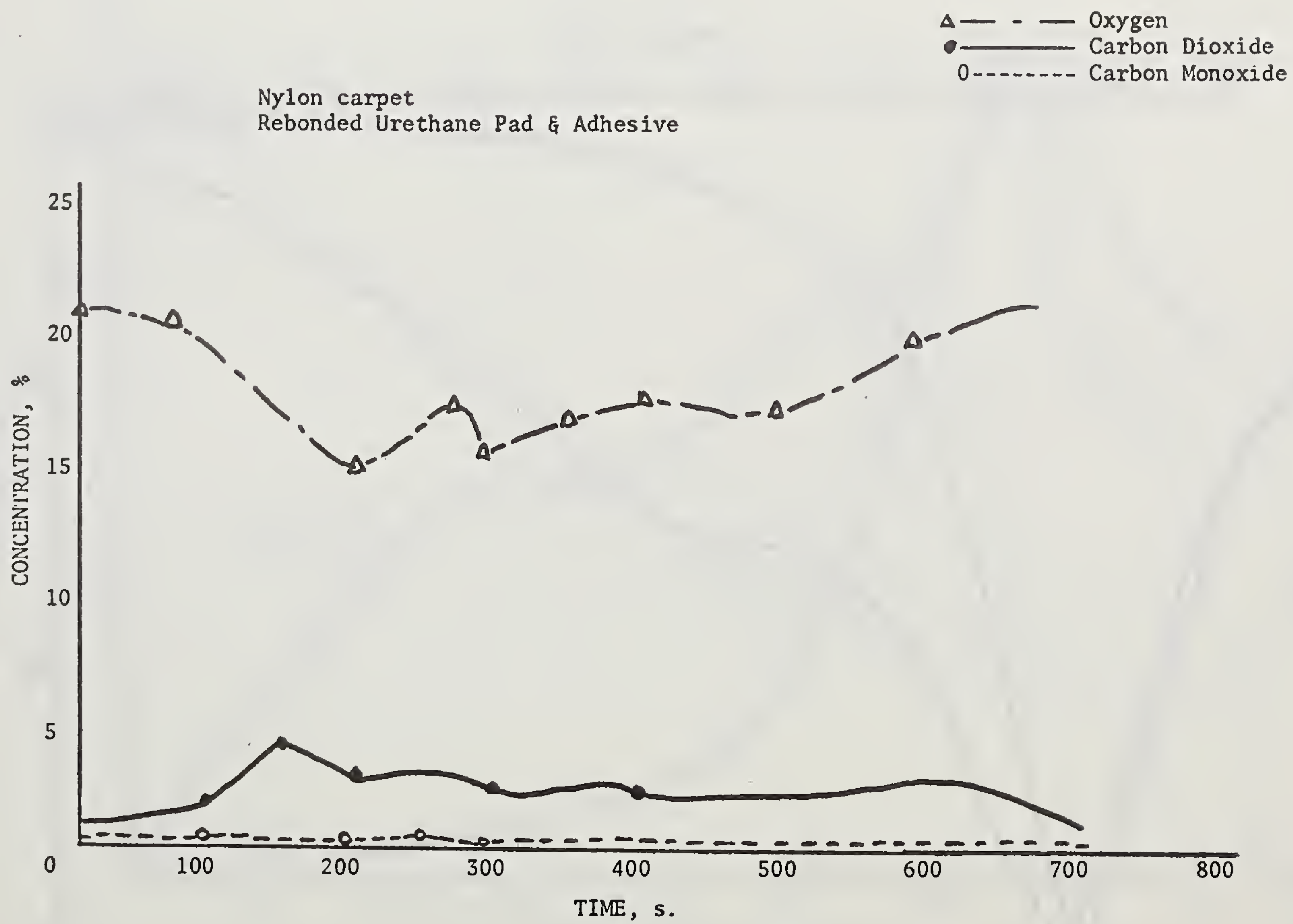

Figure 31. Test No. 362 — Continuous Gas Monitoring Data

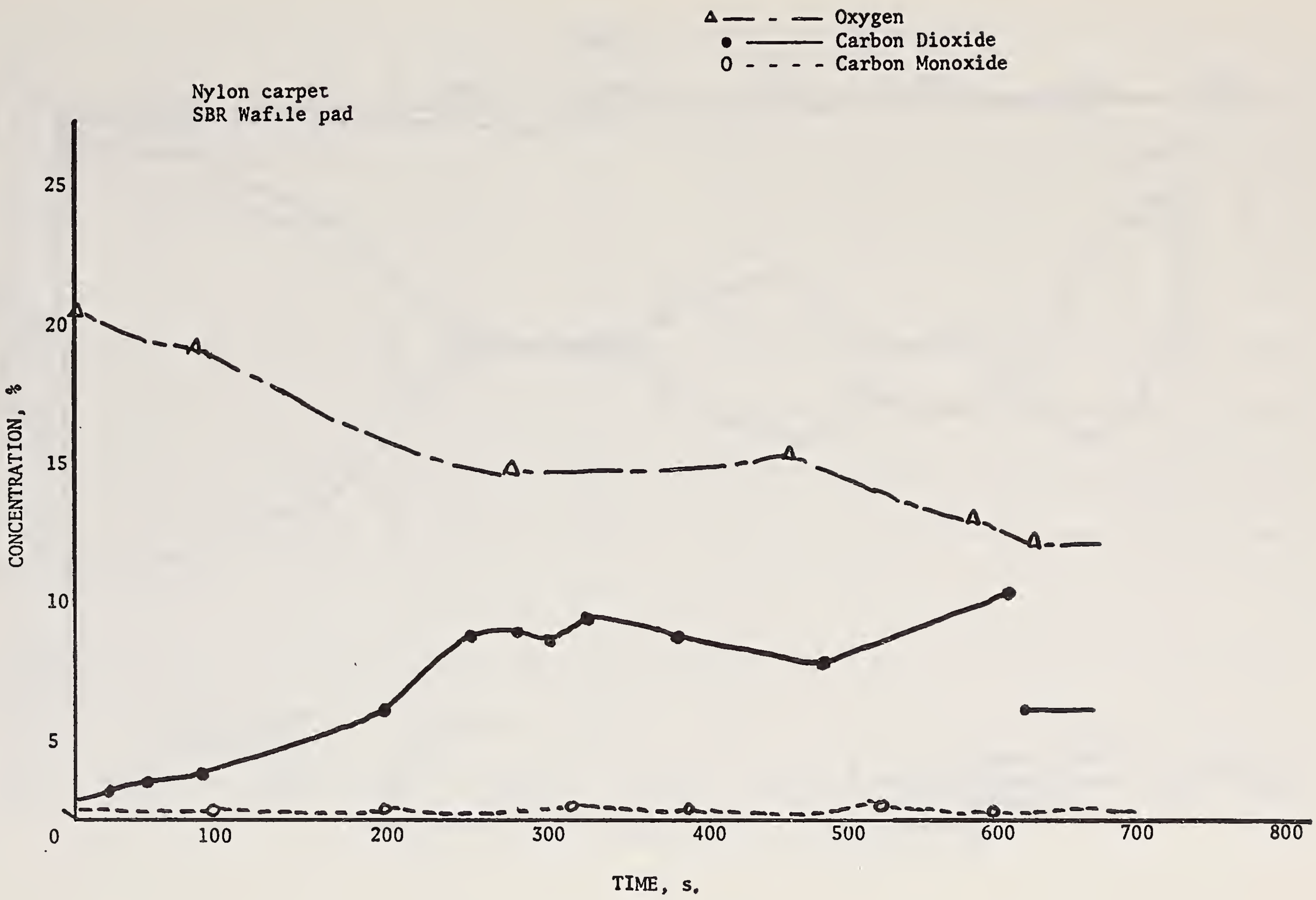

Figure 32. Test No. 367 — Continuous Gas Monitoring Data

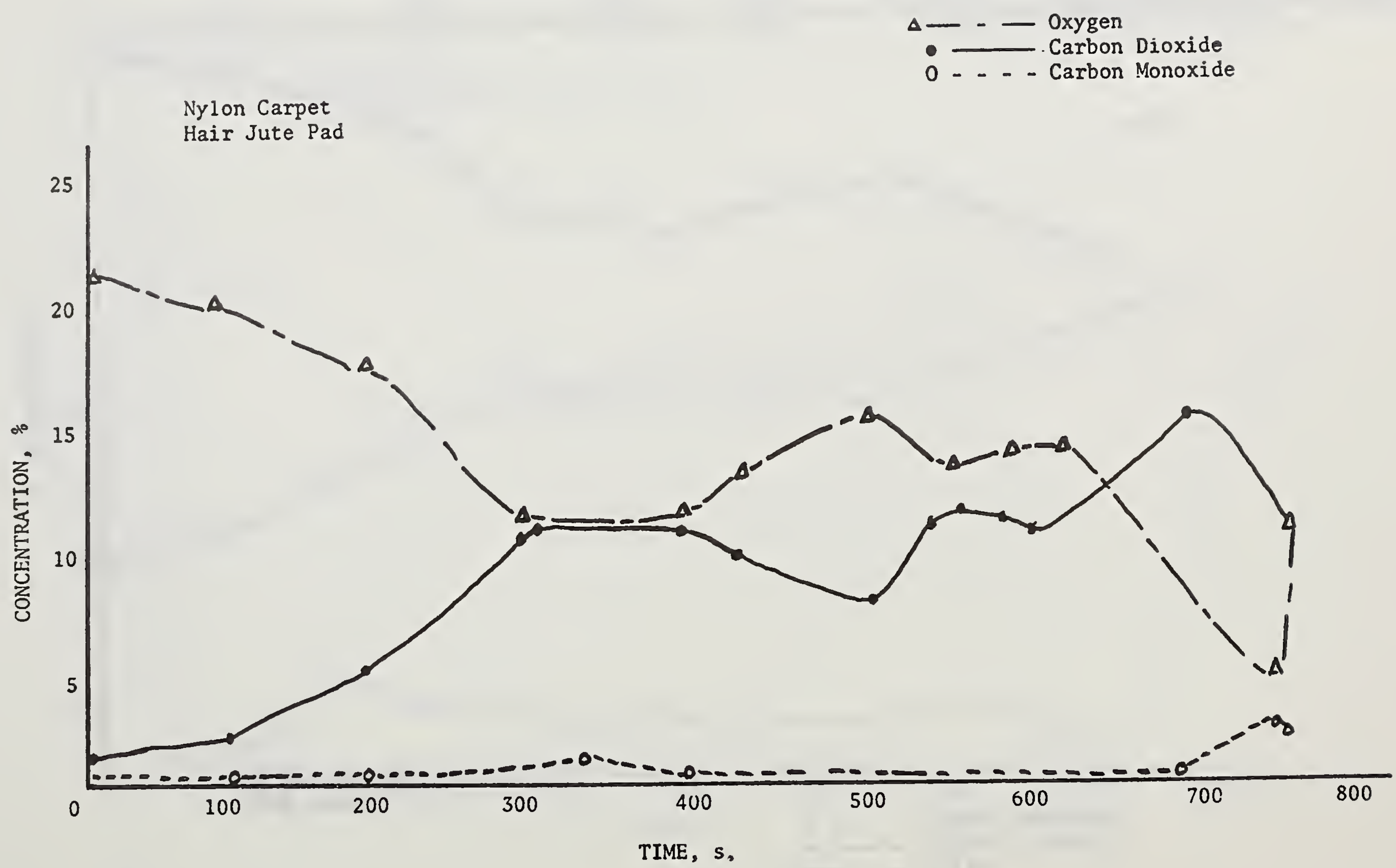

Figure 33. Test No. 368 — Continuous Gas Monitoring Data

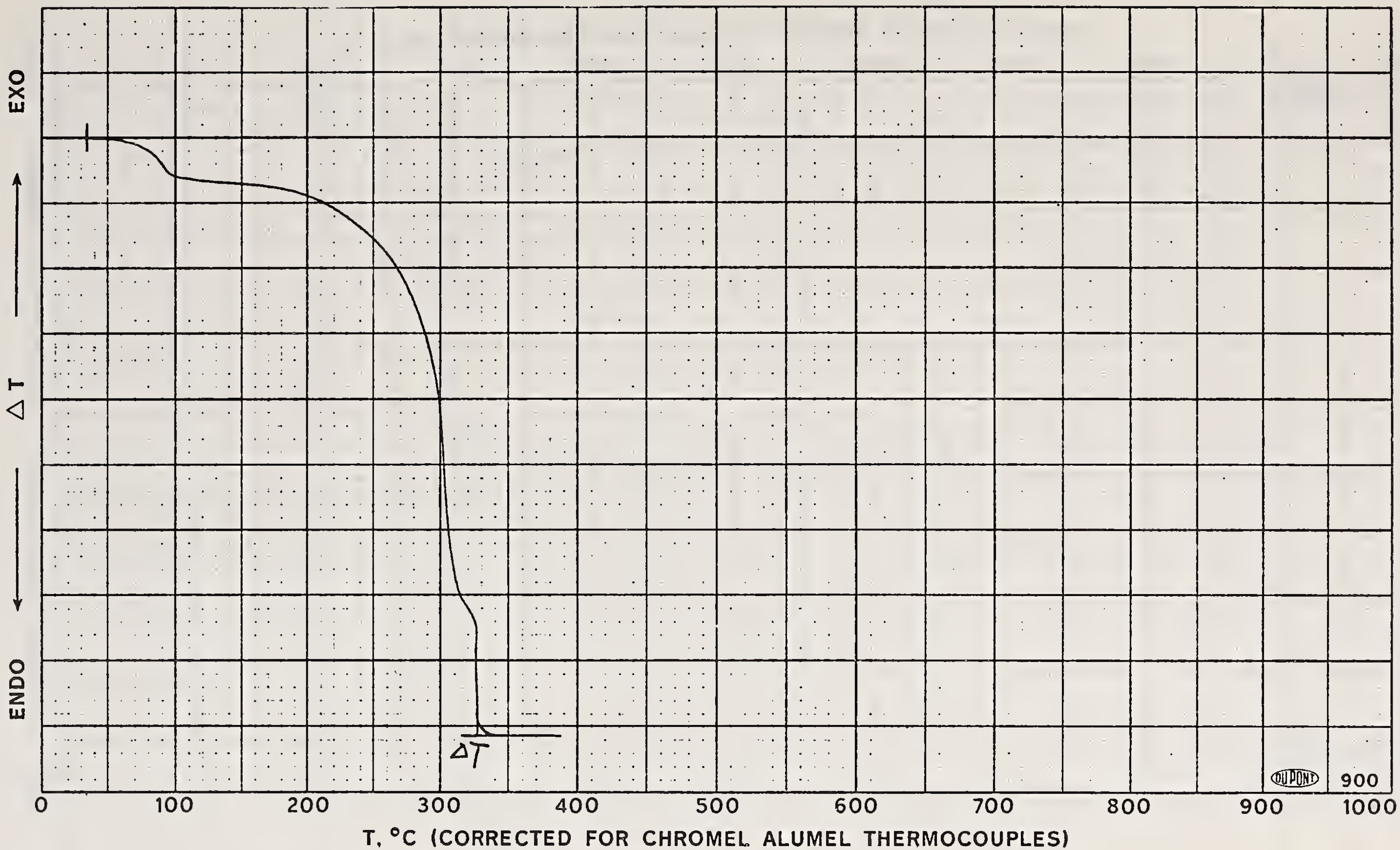

Figure 34. TGA — Hair Jute

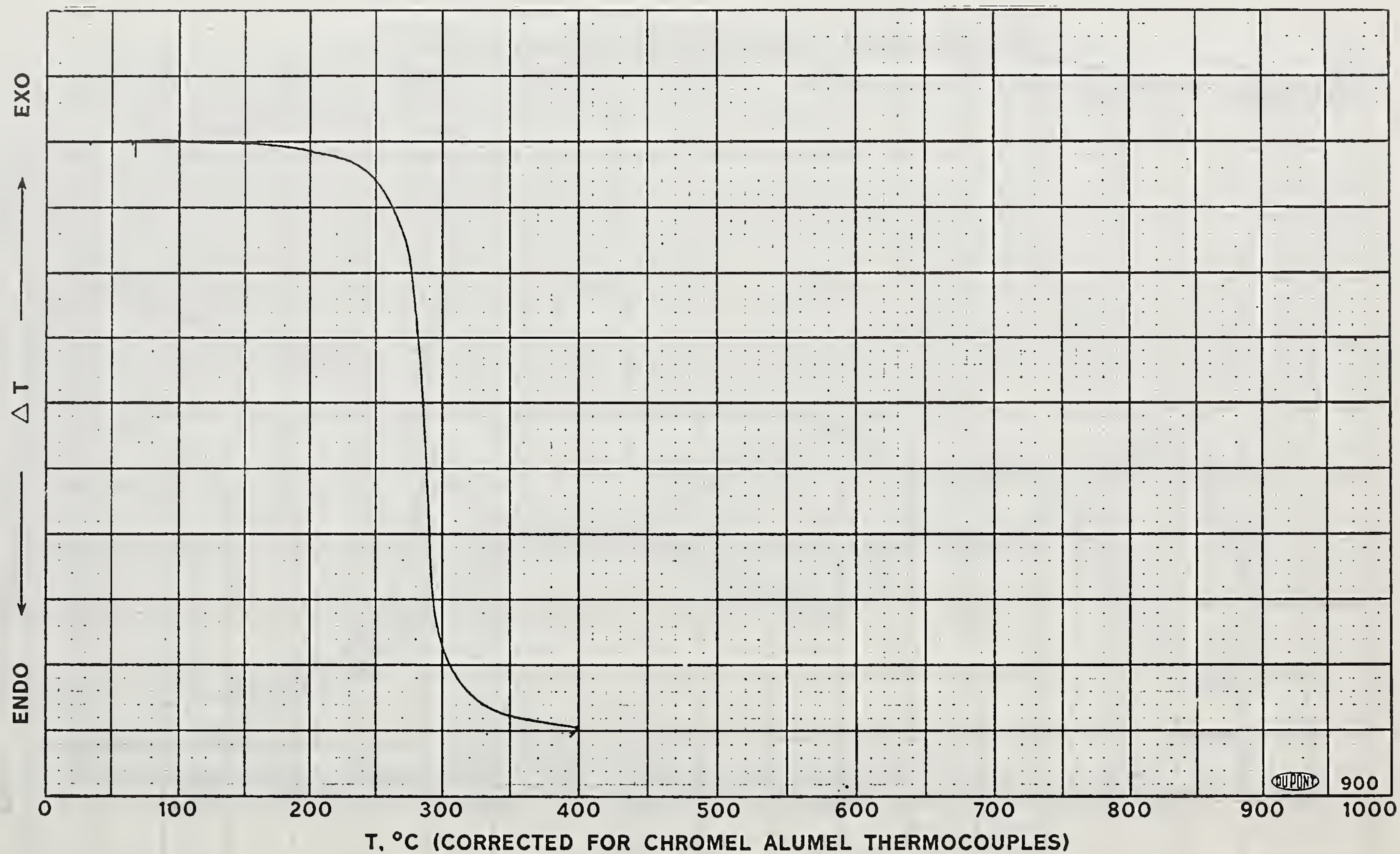

Figure 35. TGA — Virgin Urethane

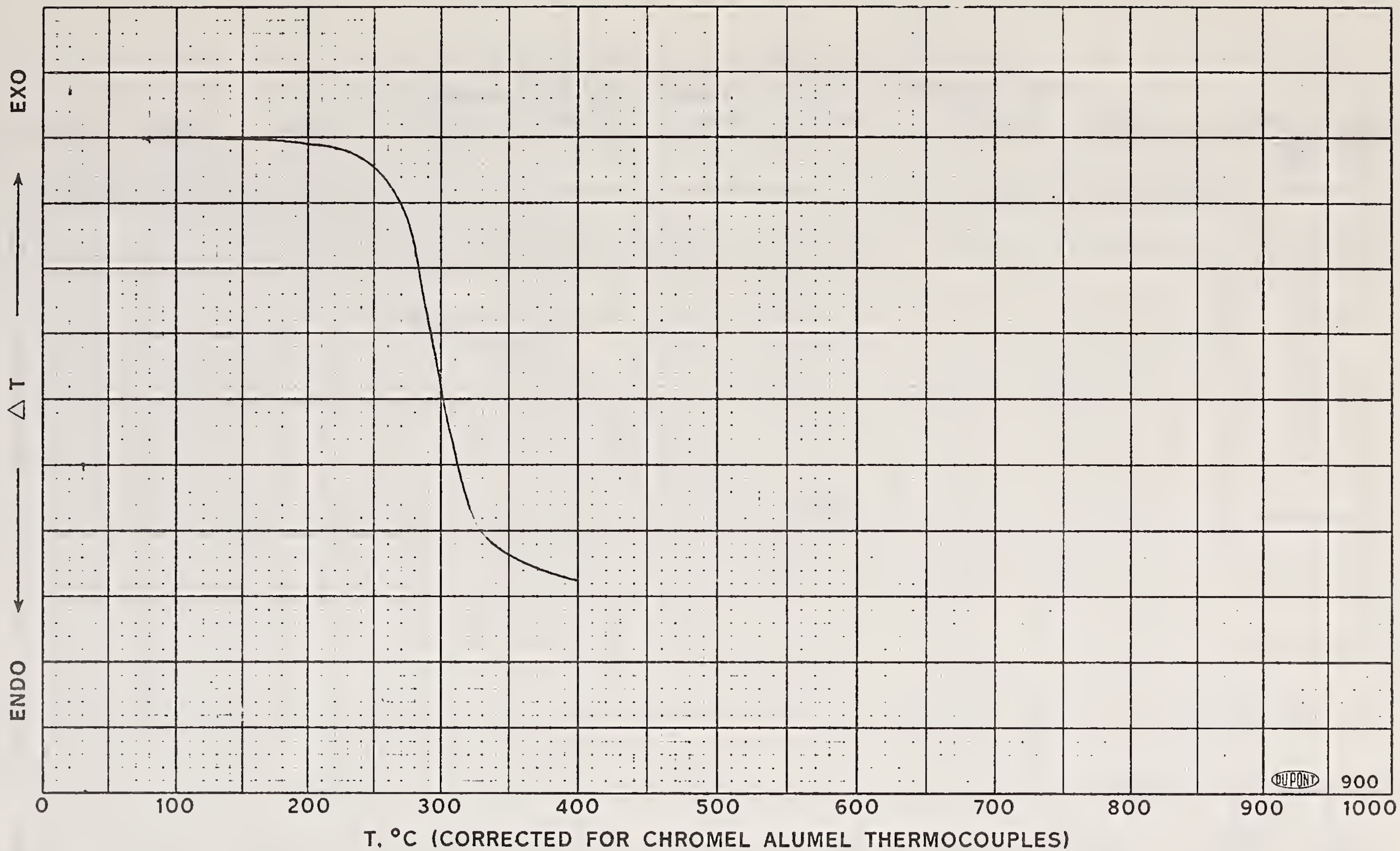

Figure 36. TGA — Rebonded Urethane

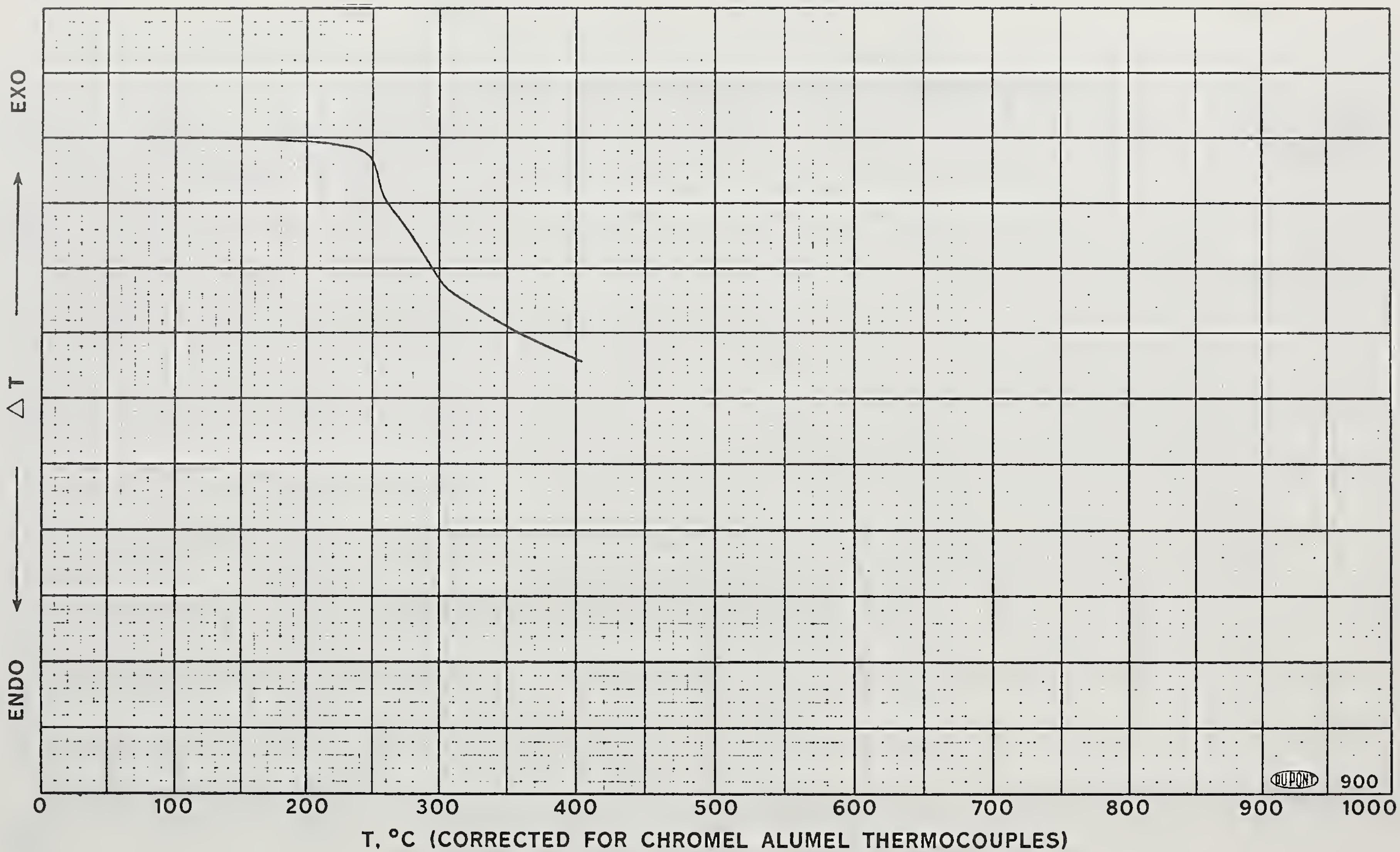

Figure 37. TGA — Latex (Backing)

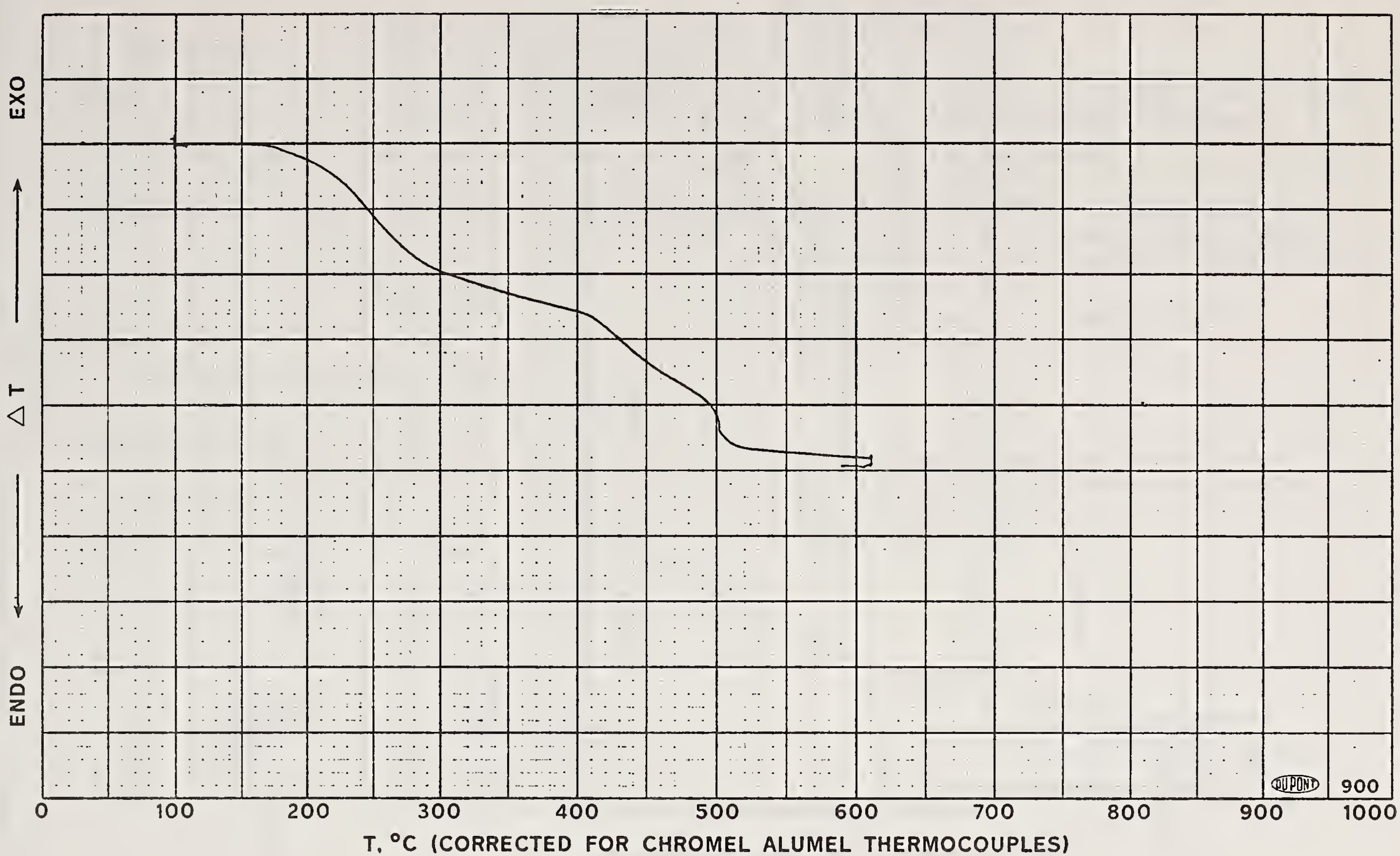

Figure 38. TGA — SBR Rubber

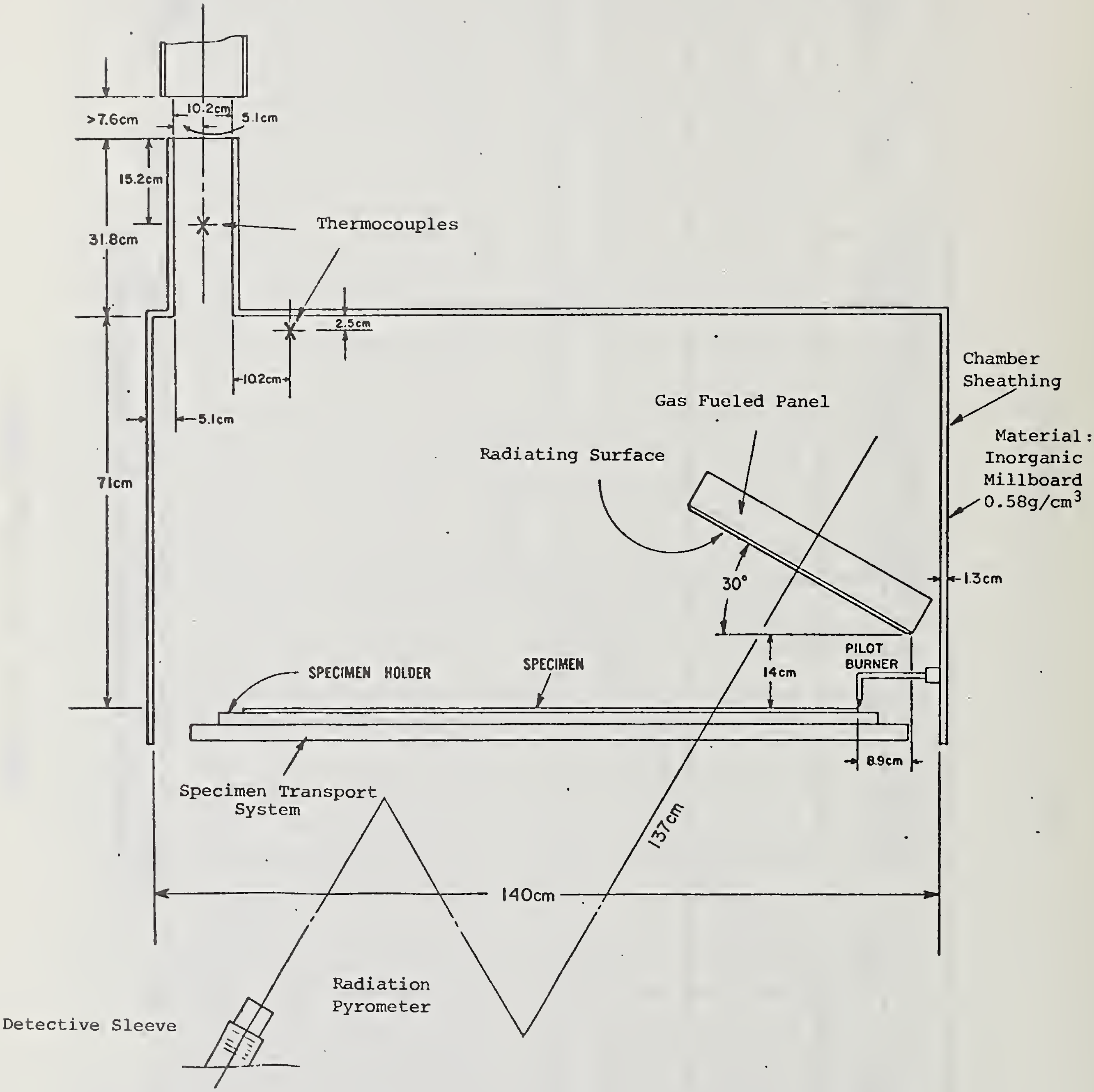

Figure 39. Flooring Radiant Panel Tester Schematic Side Elevation

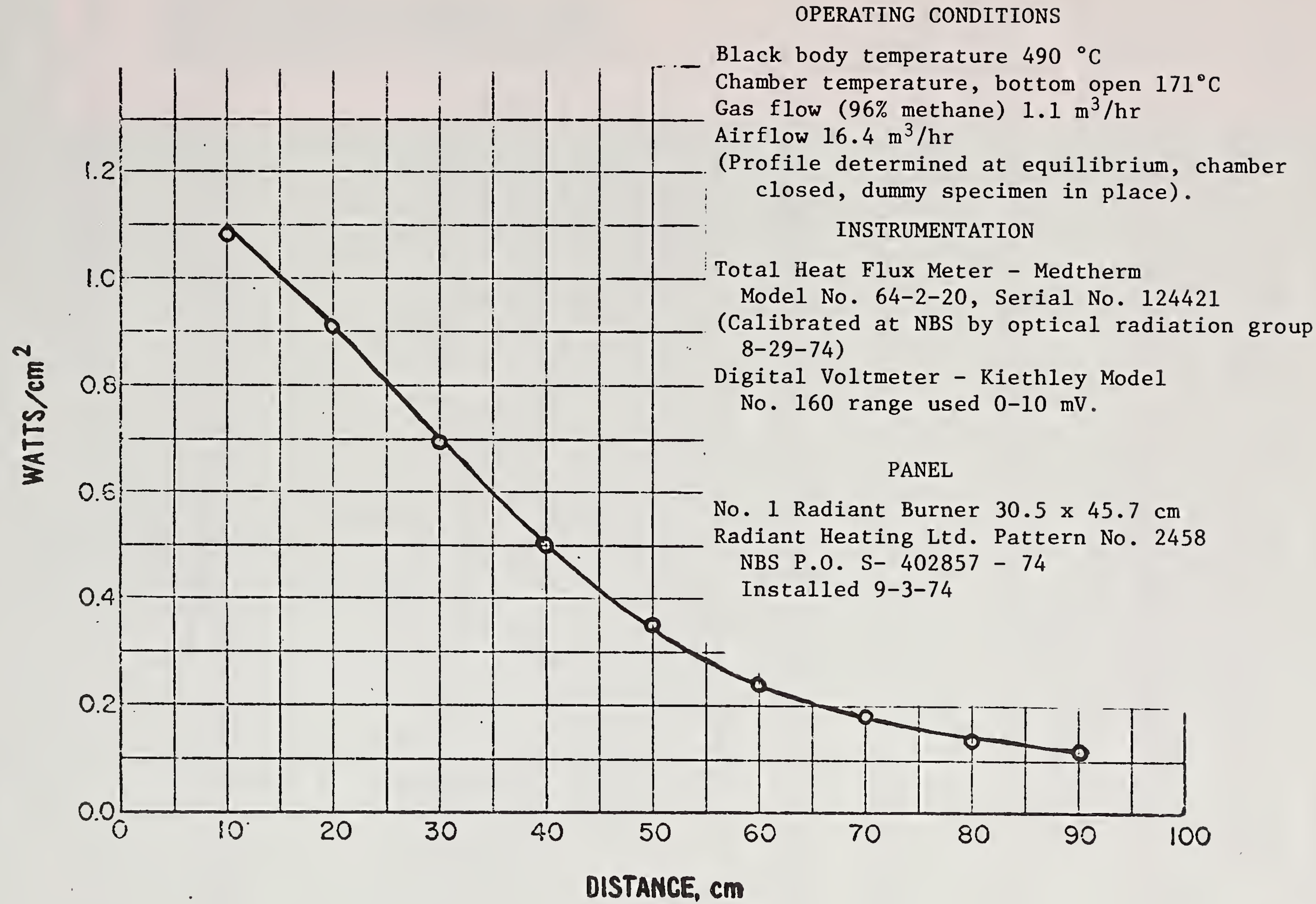

Figure 40. Standard Radiant Heat Energy Flux Profile

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A series of carpet underlayments was evaluated for fire performance in a corridor configuration using the same carpet in all tests. Carpets with underlayments flashed over during corridor tests. In a series of small-scale tests, such as the smoke density chamber and the radiant panel, the flammability properties of the carpet tended to mask the flammability properties of the underlayment. The exception to this masking effect was the results from the flooring radiant panel test where the thermal conductivity of the underlayment influenced the burning characteristics of the carpet. High concentrations of toxic combustion products were observed at the time of flashover in the corridor, with both cellulosic and synthetic underlayments. Smoke optical density values for the various carpet plus underlayment combinations were approximately the same in the flaming mode, except for the integral pad system which has a higher value.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Carpets; fire; flammability; floor coverings; pad; underlayments.

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